University College of Southeast Norway

SEFS - Fundamentals of Systems Engineering (Fall 2018)

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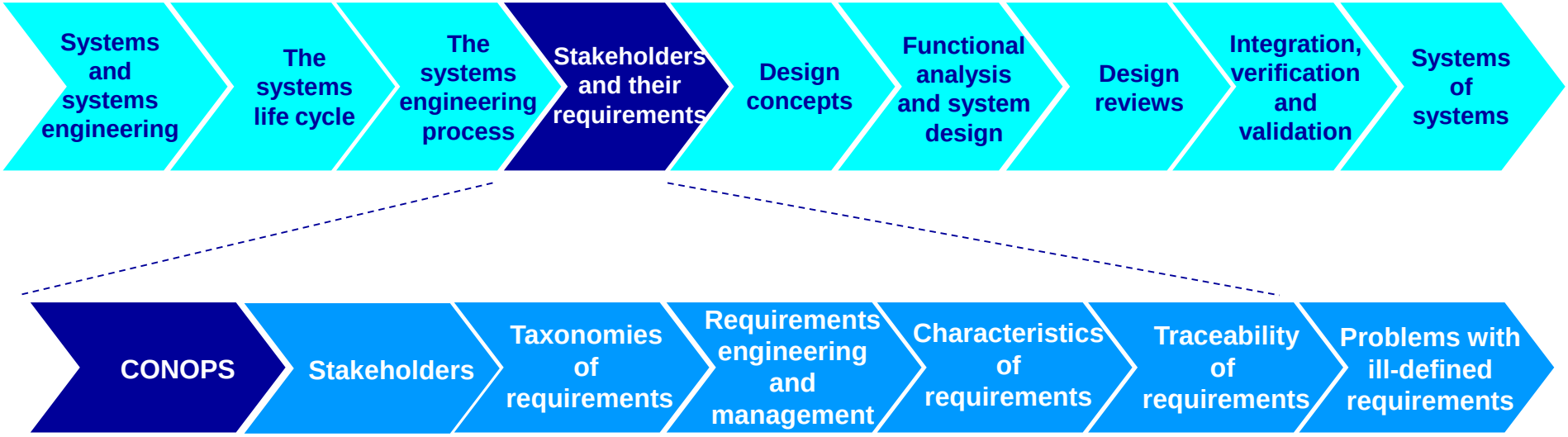
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The systems life cycle
The systems engineering process
Stakeholders and their requirements
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Requirements engineering and management
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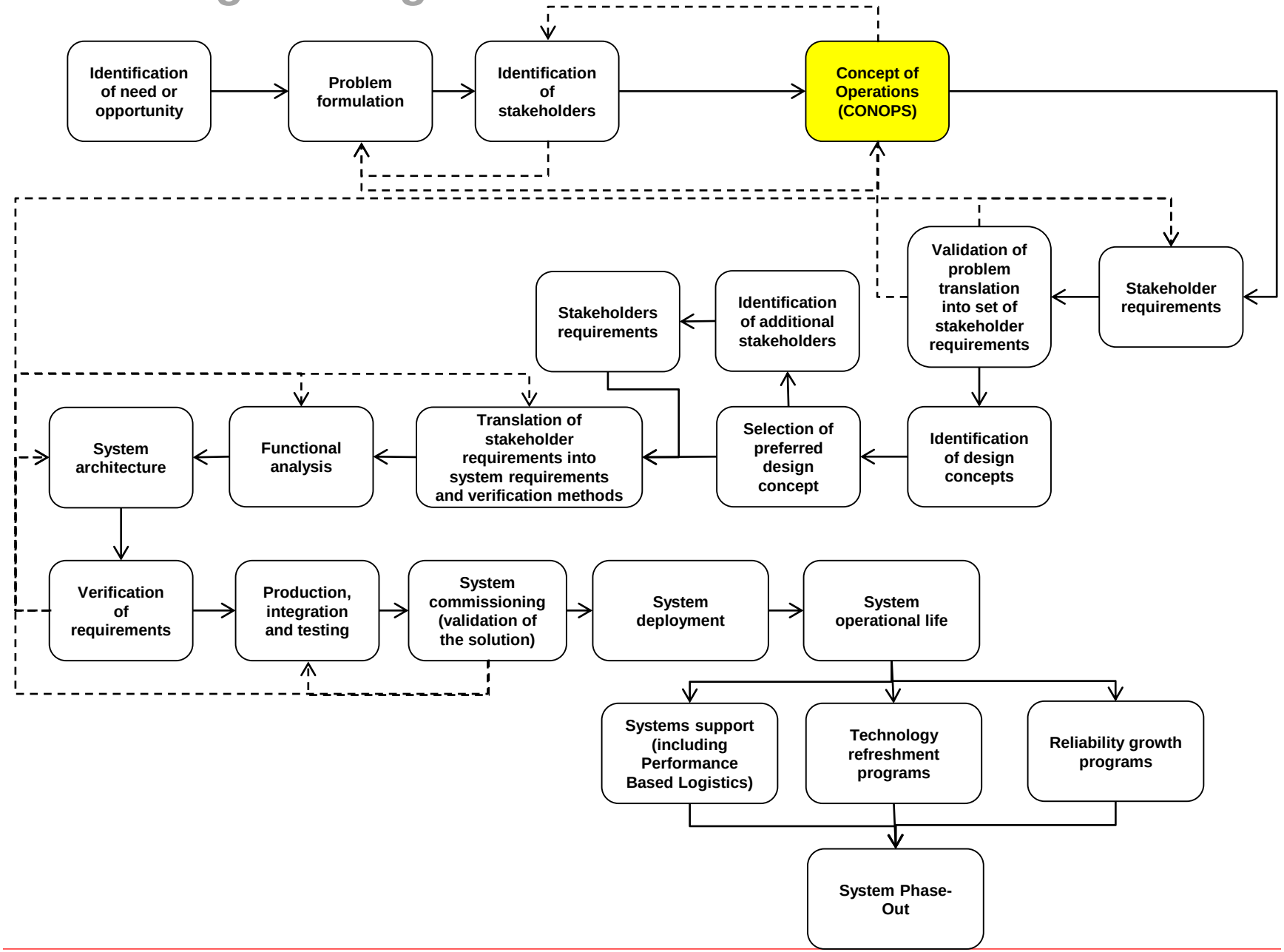
Problems with ill-defined requirements

Systems engineering framework



CONOPS

- **Concepts of Operations (CONOPS) is a document that identifies the relationship, dependencies, and desired interfaces envisioned between the new or upgraded system and other existing or planned systems. It may address an operation or a series of operations.**

- **The system is still a ‘black box’, representing whatever will eventually fulfill the perceived need or opportunity.**

CONOPS

- **Drafting a CONOPS allows users to better understand their own need and to identify important aspects of the system to be developed.**
- **CONOPS allows as well the identification of stakeholders.**

CONOPS

- **A CONOPS is a user-oriented document that focuses on the boundaries and external interfaces of the system and that describes, from the perspective of the user, the characteristics of the system to be designed. It also describes the operational profiles that the system may be assigned.**

- **It is a document that describes the characteristics for a proposed system from the viewpoint of the customers who will use it or of the stakeholders who will interact directly with it, who could influence its performance, or who could be affected by it.**

- **A CONOPS describes the as-is or current situation and the to-be or desired one.**

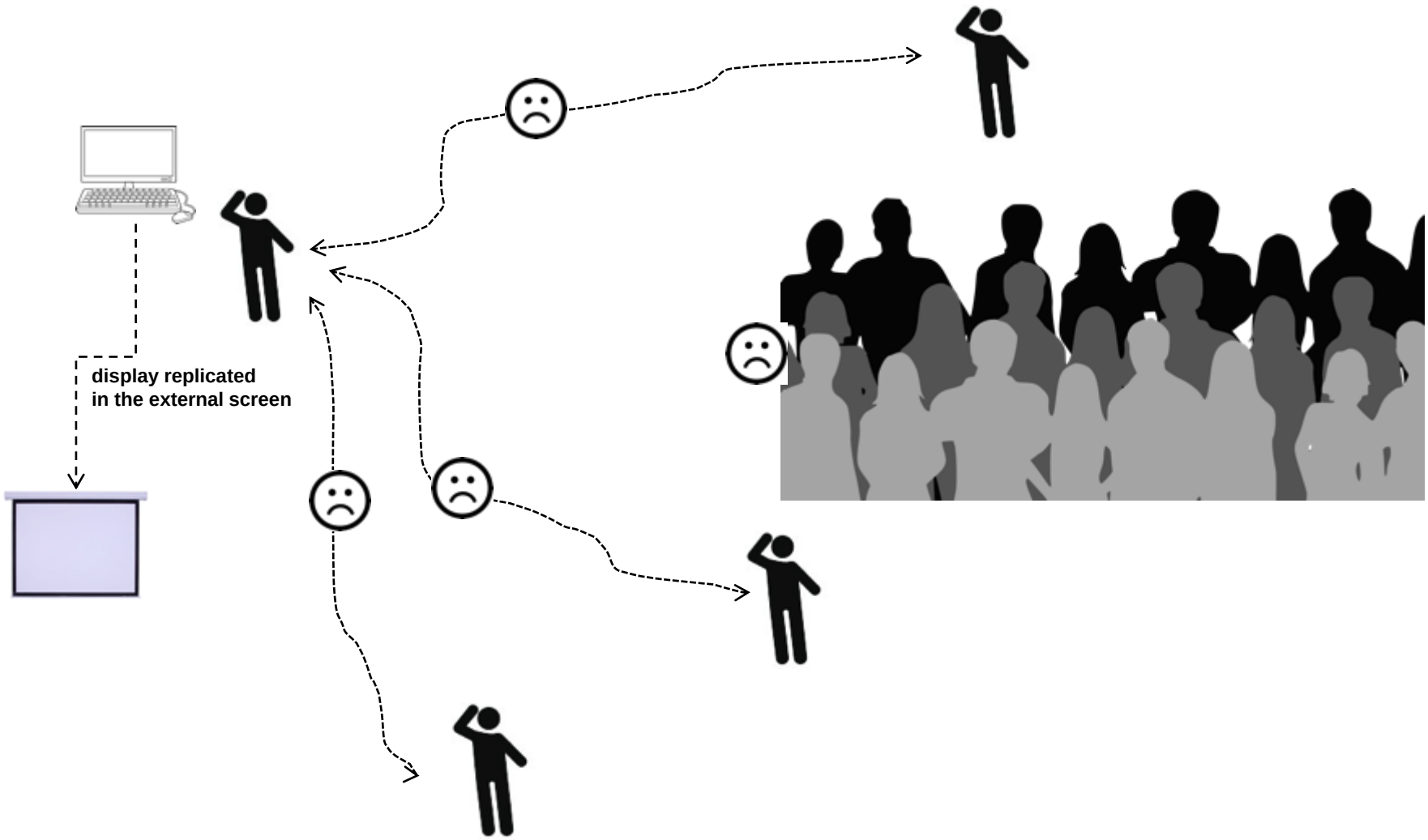
CONOPS

Contents of CONOPS
1. Statement of the goals and objectives of the system.
2. Boundaries of the system and its external interfaces.
3. Stakeholders (and interactions between them).
4. Policies and/or constraints that affect the system or that influence it.
5. Conceptual view of the system (including, if appropriate, its operational architecture).
6. Processes involved in fielding, commissioning, using, maintaining and retiring the system.

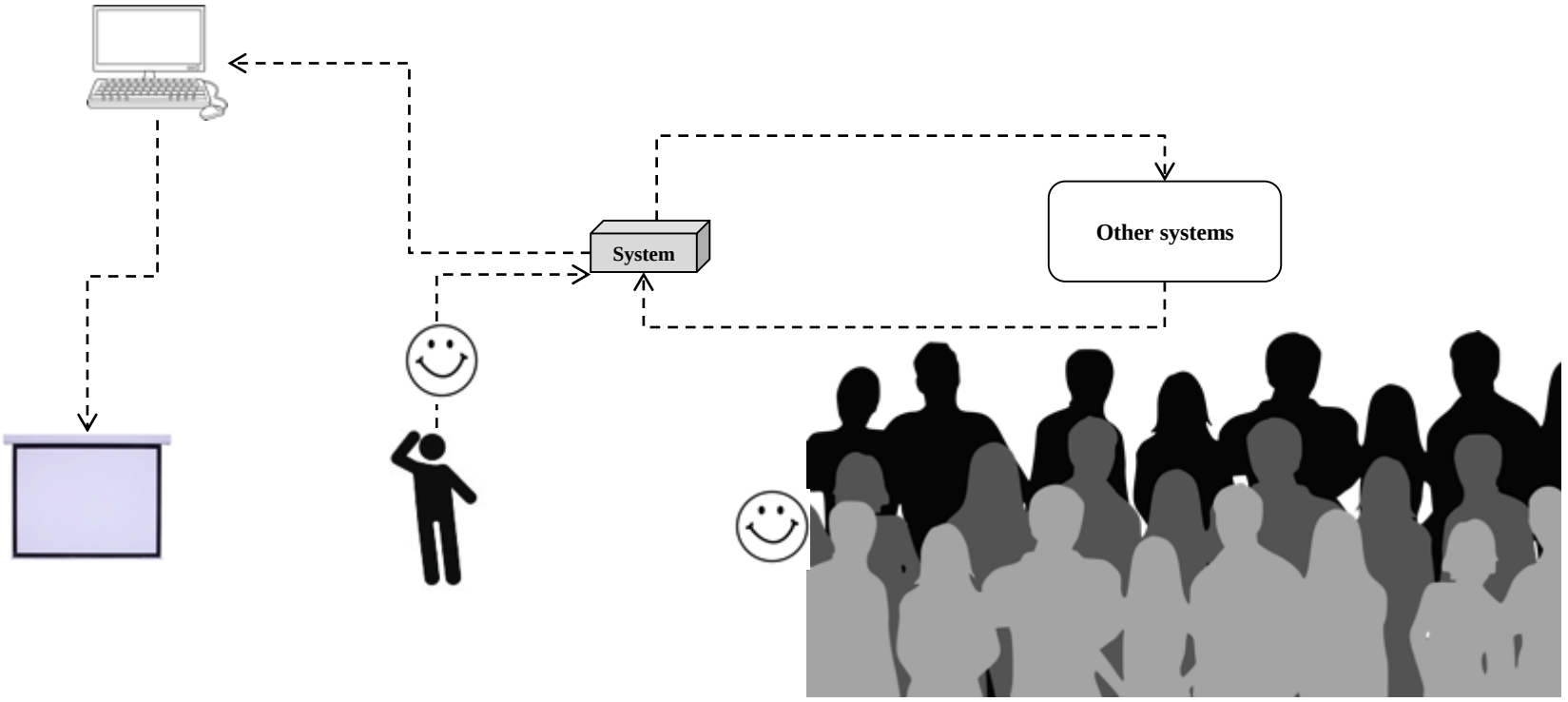
CONOPS - example

- **Let us assume we identify a business opportunity: giving lecturers and presenters certain remote control capabilities.**
- **We start thinking about what the eventual system should do, how it would interact with user and with other stakeholders or systems, ...**
- **At this stage, the system is just a ‘black box’ ....**

CONOPS – example ‘As is’

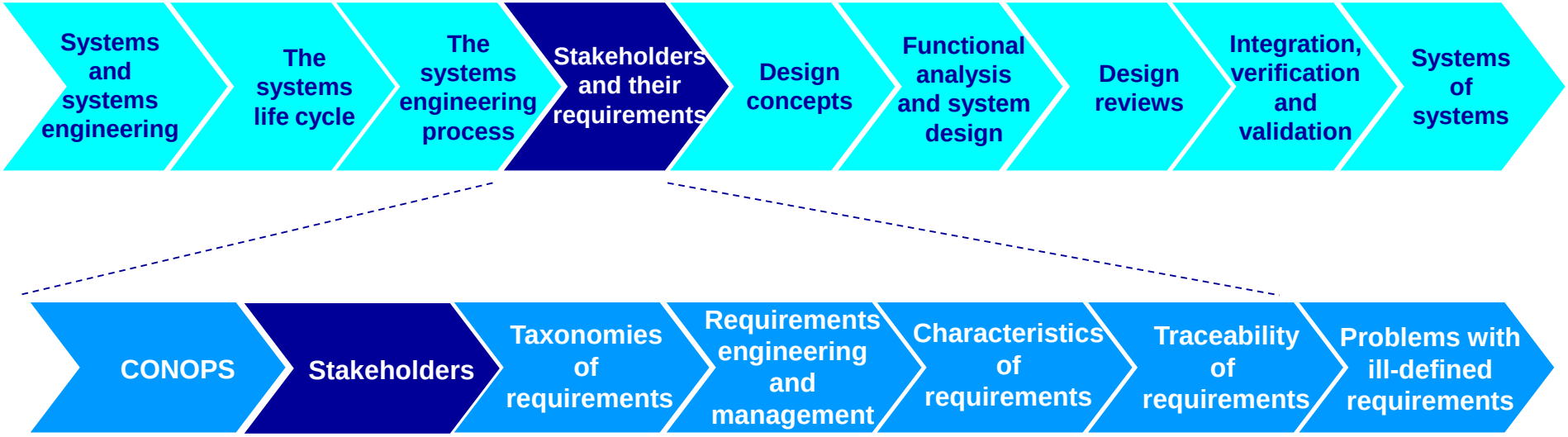


CONOPS – example ‘To be’



Case study: night vision

- **Human beings see reasonably well in daylight, but not in the dark.**
- **Night vision is the ability to see in low light conditions, or even in the absence of light.**
- **There are many users, in many different environments, who have experienced some kind of operational limitations or deficiencies associated with our lack of natural night vision capability.**
- **The identified problem or perceived business opportunity is translated into a goal that is formulated as follows: *To provide a wide number of potential end users, in both military and civilian environments, with a user-friendly, affordable, reliable and inconspicuous capability of seeing in the absence of daylight*.**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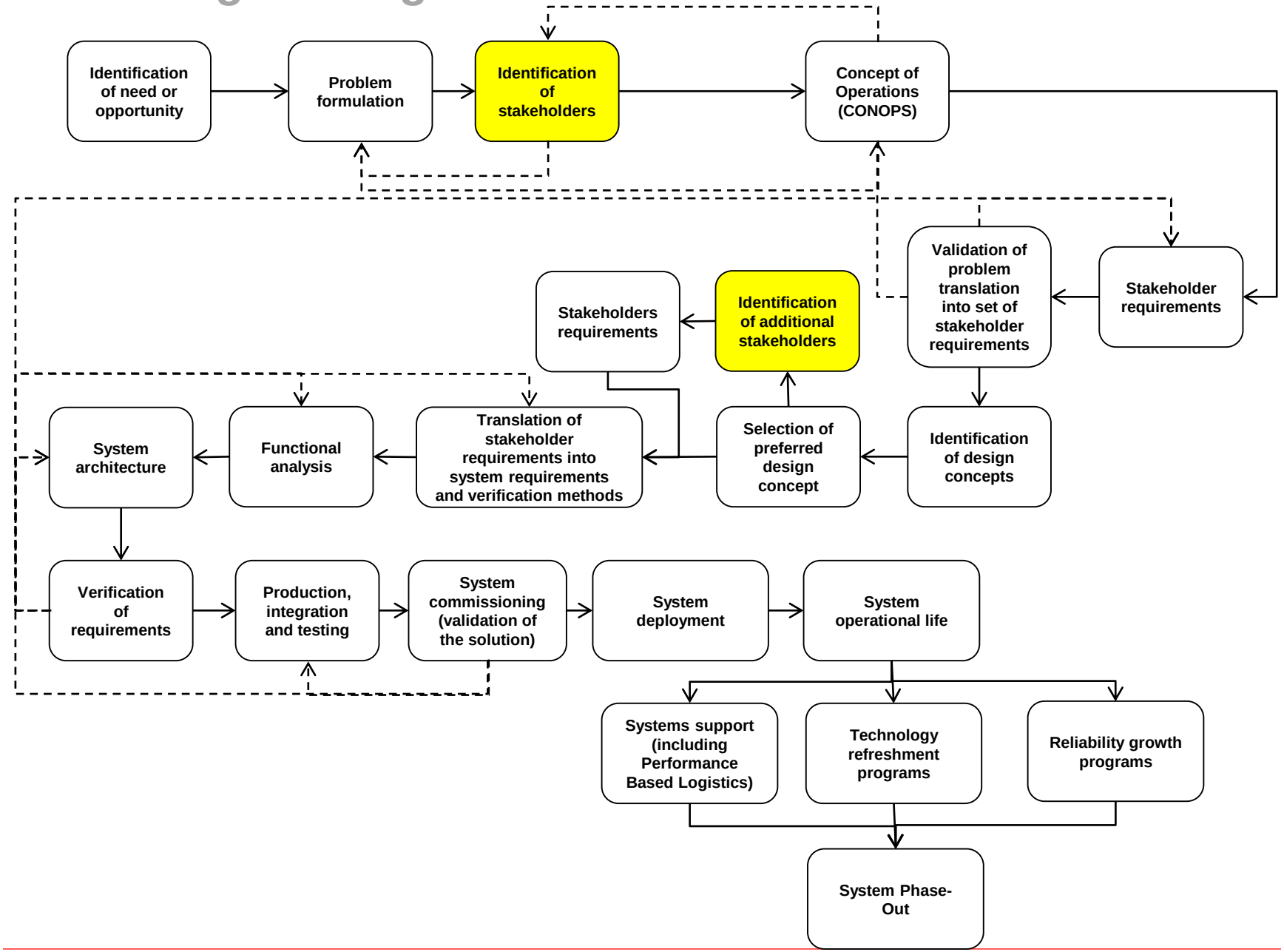
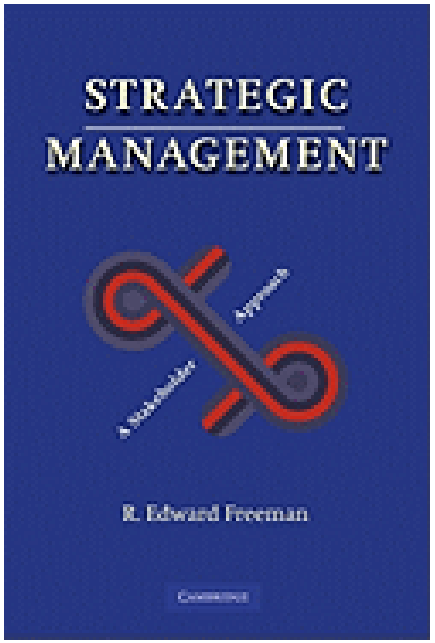


Stakeholders



- **Term introduced in 1984 by R. Edward Freeman in ‘Strategic Management: a Stakeholder Approach’.**
- **From *shareholders* to *stakeholders*.**
- ***Stakeholders* are all those persons or institutions that are interested in, affected by, or that can have influence in, the utilization of the system.**

Stakeholders

- **Not all stakeholders will issue directly requirements for the design of the system, but the system has to be designed taking them all into account!**
- **If there are several stakeholders from which requirements are obtained it is necessary to prioritize them, mainly in case of conflicts of interest.**
- **Never lose sight of the stakeholder that will pay the invoice!**

Stakeholders: example

Identified opportunity: device that would facilitate cash to customers of a bank, 24 hours per day, 7 days a week.

The origin of the MiniBank or Automatic Teller Machine, like so many other inventions, is not free of some controversy. Don Wetzel filed a patent in the States in 1968. Initially it was merely a cash dispenser, to which additional functionalities were added later on.

Stakeholders: example

Example: ATM

Easy-to-think-of stakeholders:

- **User**
- **Bank personnel**
- **Security personnel**
- **Maintenance technicians**

Other stakeholders:

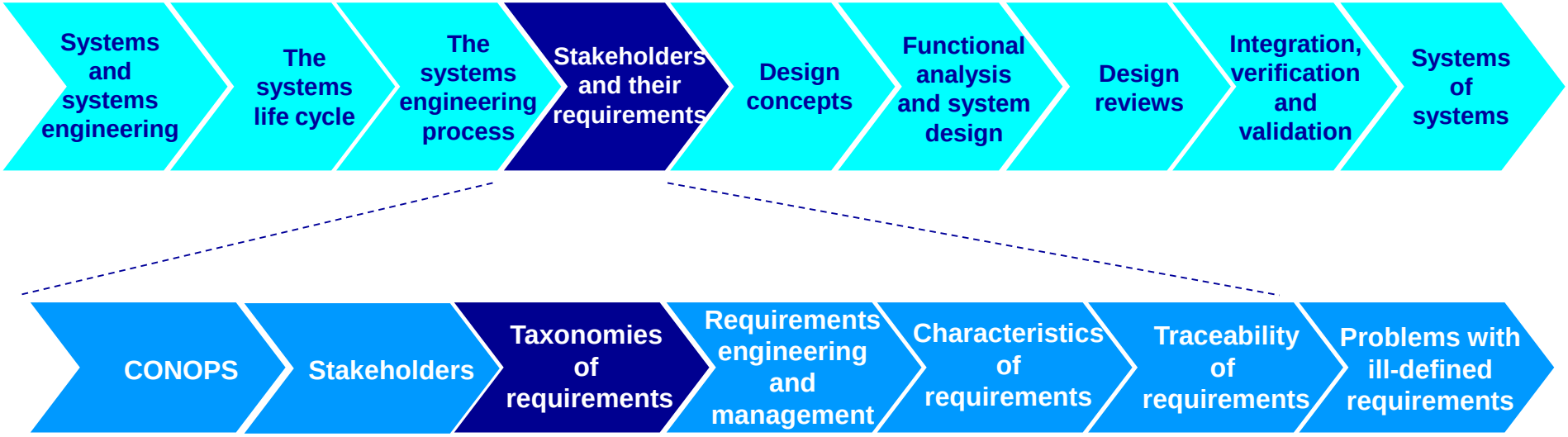
- **Bank's IT personnel**
- **Electric power supply personnel**
- **Communication networks personnel**
- **Insurance companies personnel**
- **Card companies personnel**

Case study: the stakeholders

Stakeholder	Reason	Expected input
SH-1 Internal customer or project sponsor	The project has been launched as a company initiative. A higher official in the company, such as the Managing Director, or even the Board of Directors, acts as internal customer and sponsor of the project.	Requirements from a company-wide perspective. May include image (to consolidate the name of the company as a developer of state-of-the-art products), profitability, and the like.
SH-2 External financial sponsors	In case the company lacks the financial muscle and thus seeks the support of a third party, this entity becomes a stakeholder.	Profitability expected from the investment. May depend a lot on how the financial support is articulated (for example, it may be a loan, or the purchase of a percentage of the project).
SH-3 End user of the 'night vision capability' system	End customers will indicate their desired features and performance of the 'night vision capability' artifact.	Information on intended operational environment, utilization profiles, maintainability and supportability considerations, cost considerations, and the like.
SH-4 Authorities that issue applicable legislation and regulations	Although the system is still a 'black box', for it to receive the approval for selling in the target market, it will have to meet the applicable norms dictated by the pertinent authorities.	At this stage in the life cycle, it is necessary to take into consideration the generic norms and rules that apply to products aimed at delivering night vision capabilities.

Case study: the stakeholders

Stakeholder	Reason	Expected input
SH-5 People interested in detecting the person using the 'night vision capability' system	Potential trespassers of private, protected or restricted areas. In military applications, enemies or foes of the person using the 'night vision capability' artifact.	Since these stakeholders would want to detect the users of the night vision capability artifacts, the latter will demand or expect low signatures of the 'night vision capability' artifact. These signatures could be size-related, noise-related, energy-emitted-related, and the like.
SH-6 Accredited certification companies and classification societies	These entities may take an active role in certifying the fulfillment of the norms or standards dictated by the relevant authorities, through the examination of the design documentation and the execution of the corresponding verification tests.	The type and depth of the documentation that they will demand, as proof of the fulfillment of the applicable norms and standards.
SH-7 Patent offices	There are two issues to be considered here. First, whether the intended solution is innovative and can earn the developer some intellectual property rights. Second, whether the intended solution may use some elements or technologies that have been registered, and for which authorization from the owners is needed (in form of license and royalty fees, or whatever is appropriate).	On the one hand, degree or novelty or innovation that has to be proved and substantiated, for a patent request to be granted. Type of information required so as to file a request for a patent. On the other hand, to ascertain whether parts of the proposed solution have been already registered by third parties, in which case an agreement for the right to use will have to be negotiated with them.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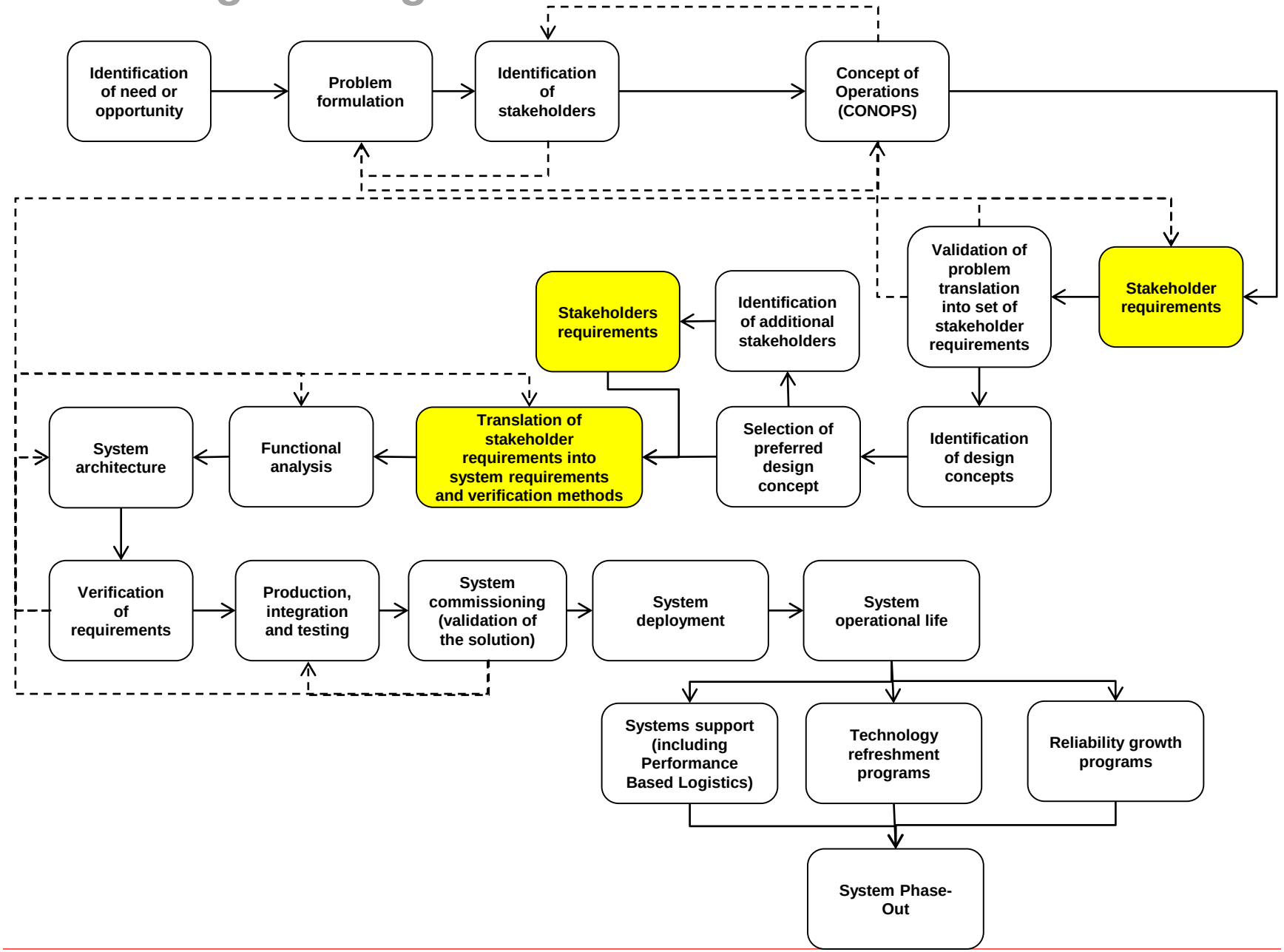
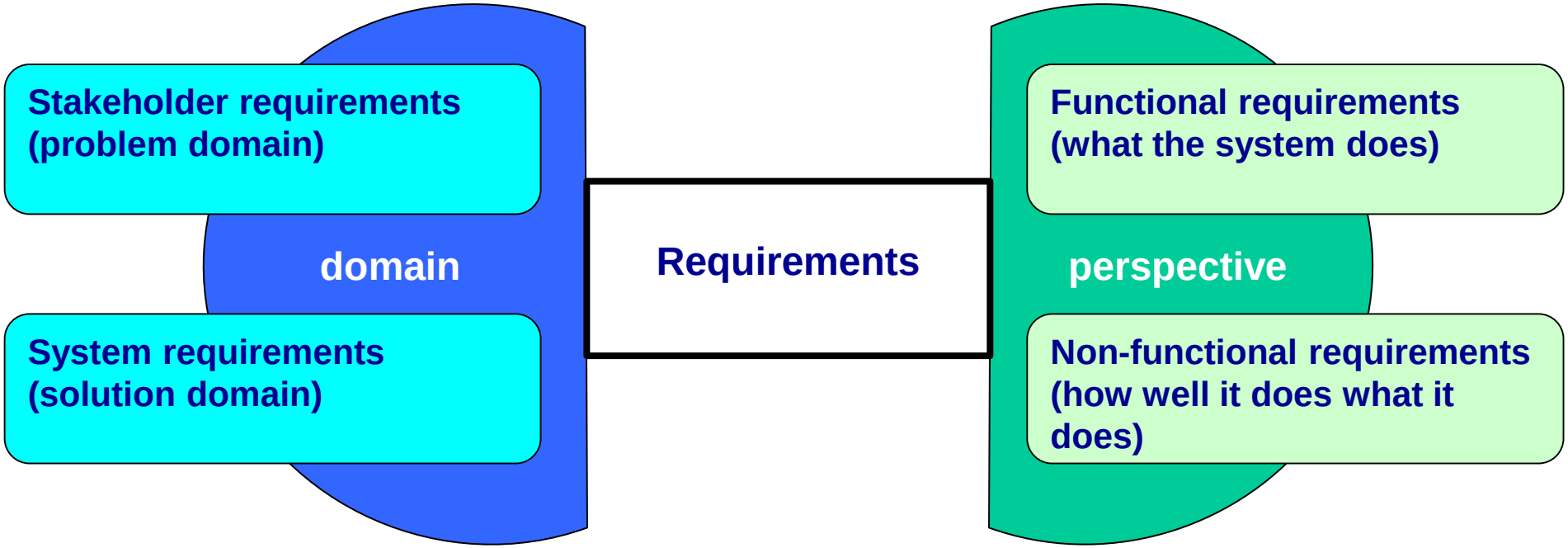
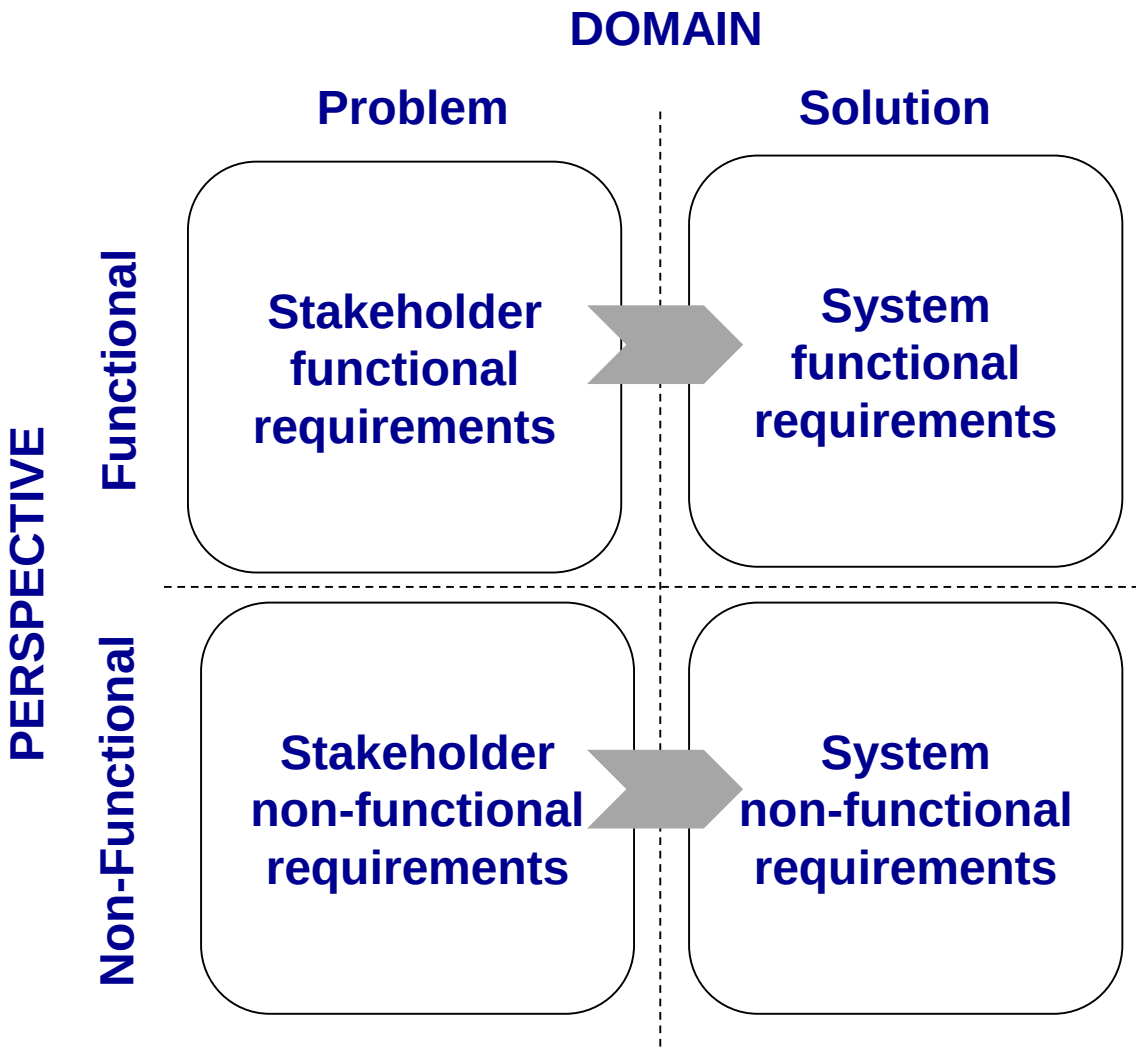


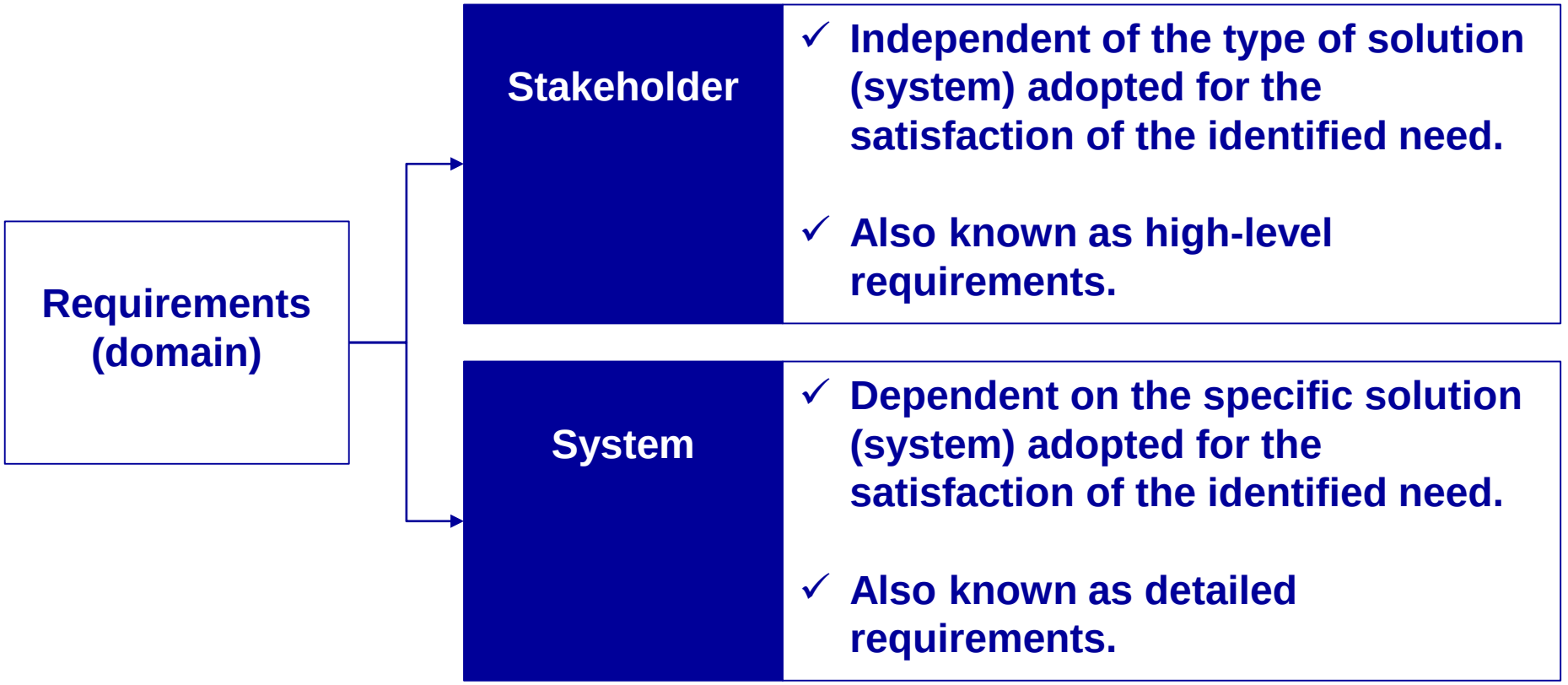
Two taxonomies of requirements



Taxonomies of requirements



Types of requirements



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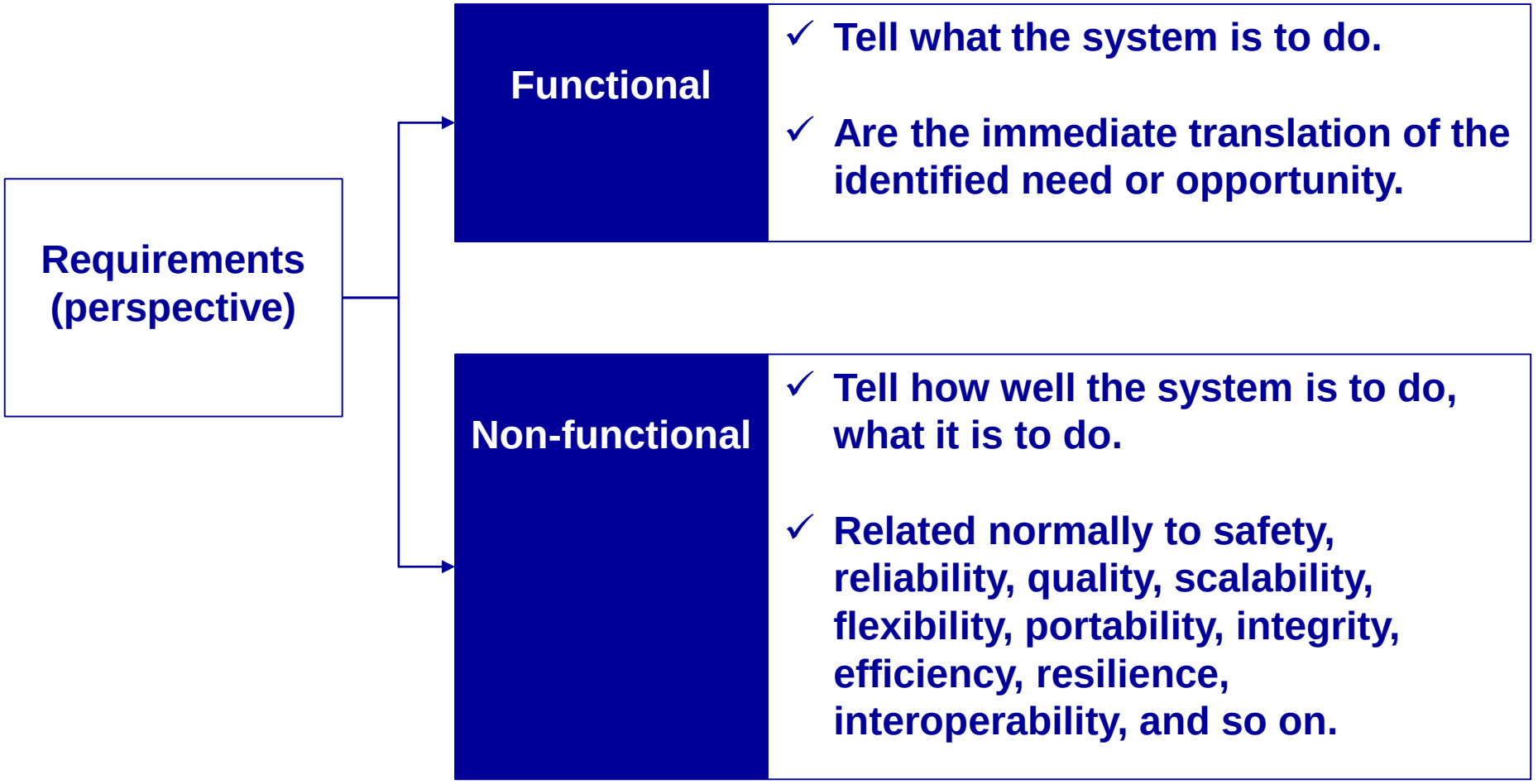
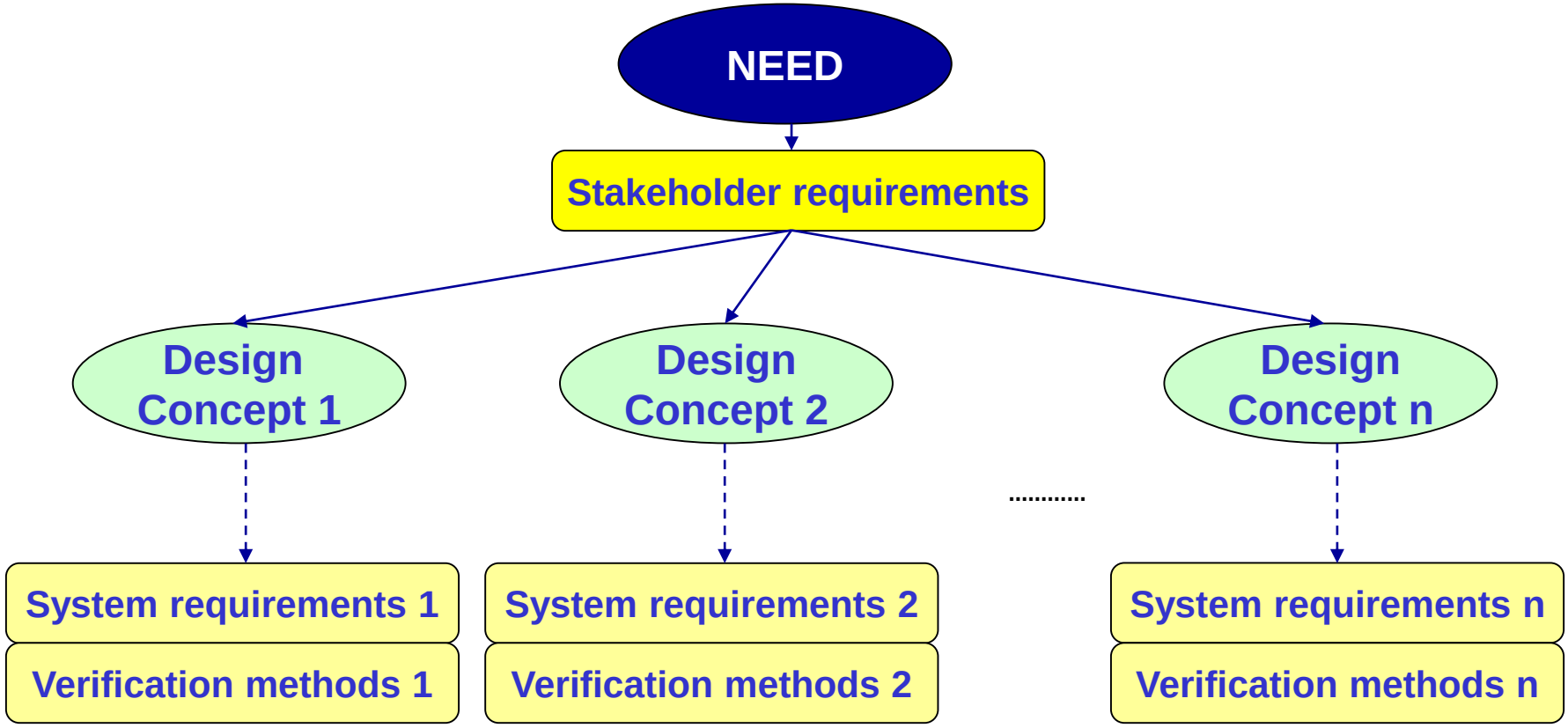
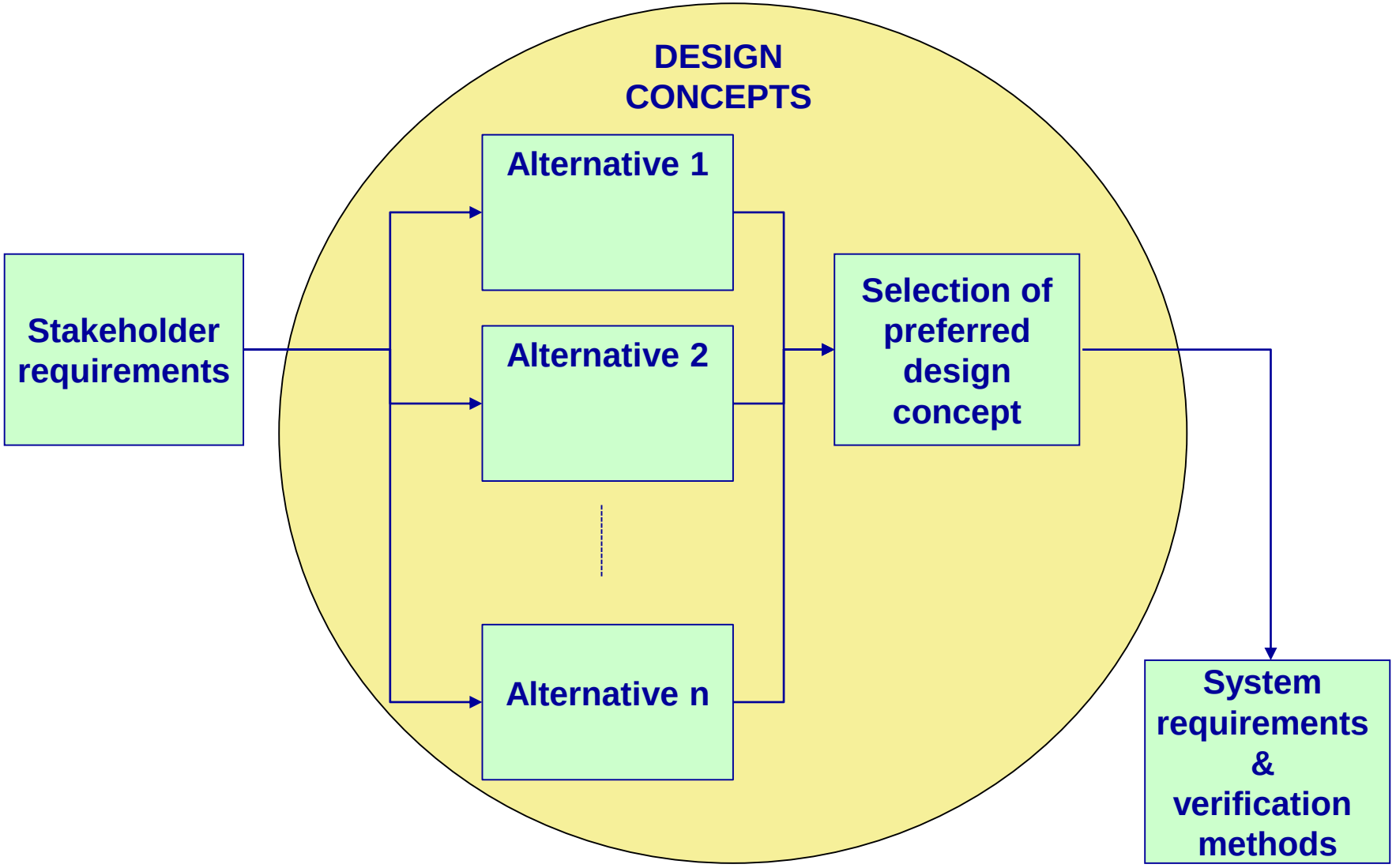


Types of requirements

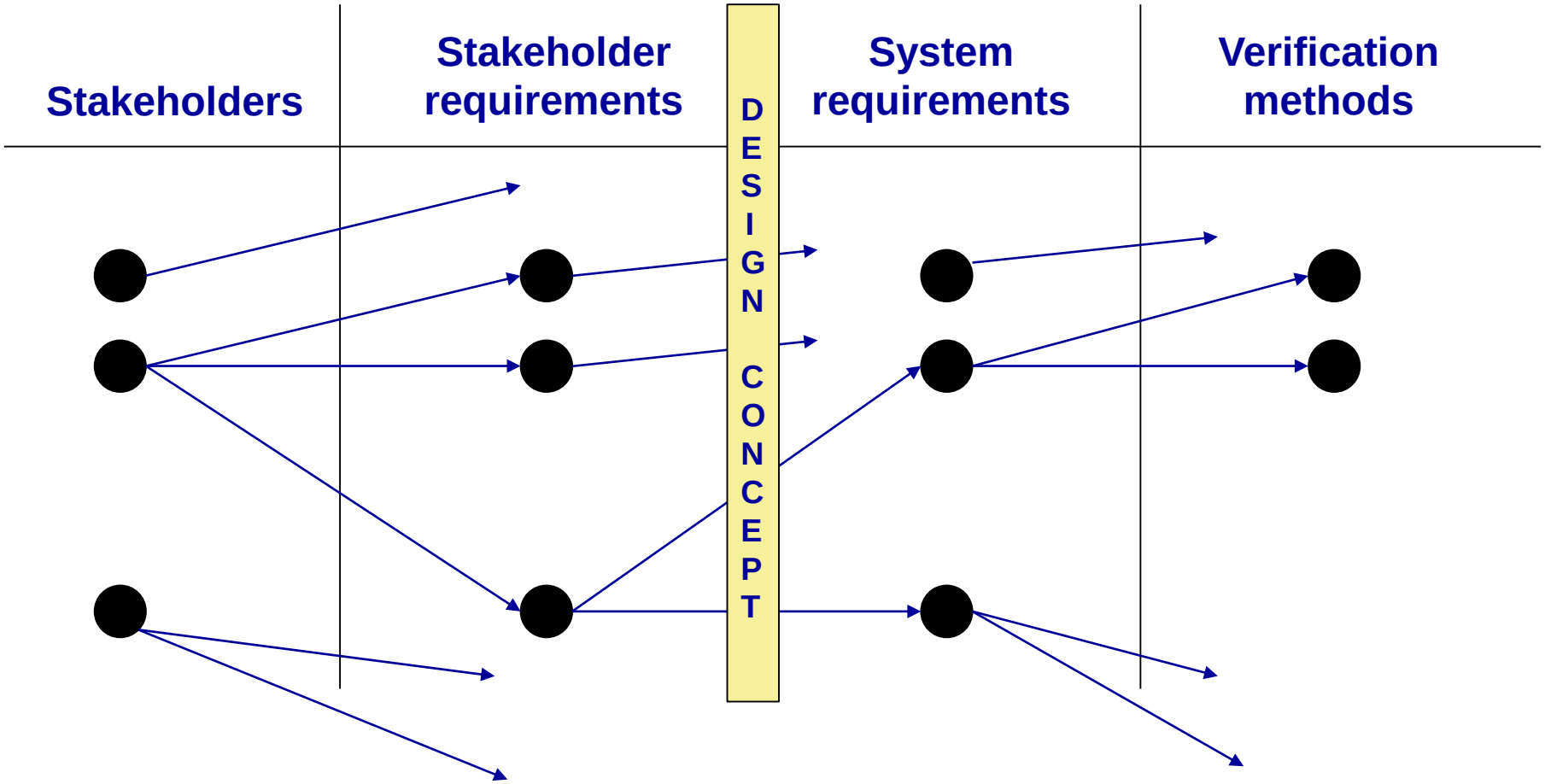
Far too often, stakeholder requirements are wrongly expressed by being associated to a potential solution or design concept!



Translation of requirements



Relationships



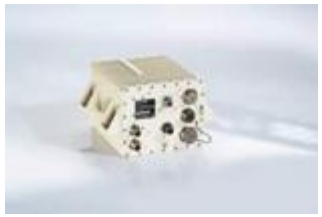
- They normally are 1-to-many.
- Some times a child may have two or more parents.

Example of requirements

- **Stakeholder requirement: The system should know its position at all times.**

- **There are at least two options: inertial navigation systems (INS), and GPS receivers. The system requirements will depend on the specific solution adopted:**

INS



- **Weight less than 6 kg.**
- **Input voltage 28 V DC.**

GPS receiver

- **Weight less than 350 gr.**
- **Battery autonomy of at least 48 hours.**

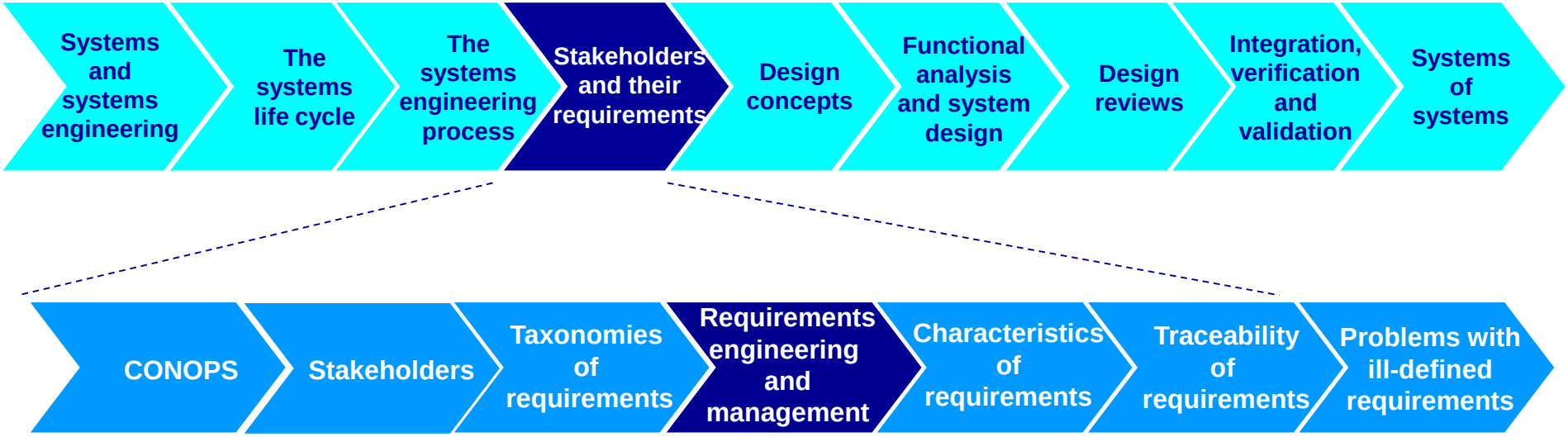
Stakeholder requirement: an example

“Put a man on the Moon …. and bring him back safe back to Earth … before the end of the decade”

John F. Kennedy
Discourse at Rice University
Houston (Texas)
September 12, 1962

Translate need or opportunity into requirements

The crux of the matter is the complete translation of the identified need or opportunity into the correct set of solution-independent requirements.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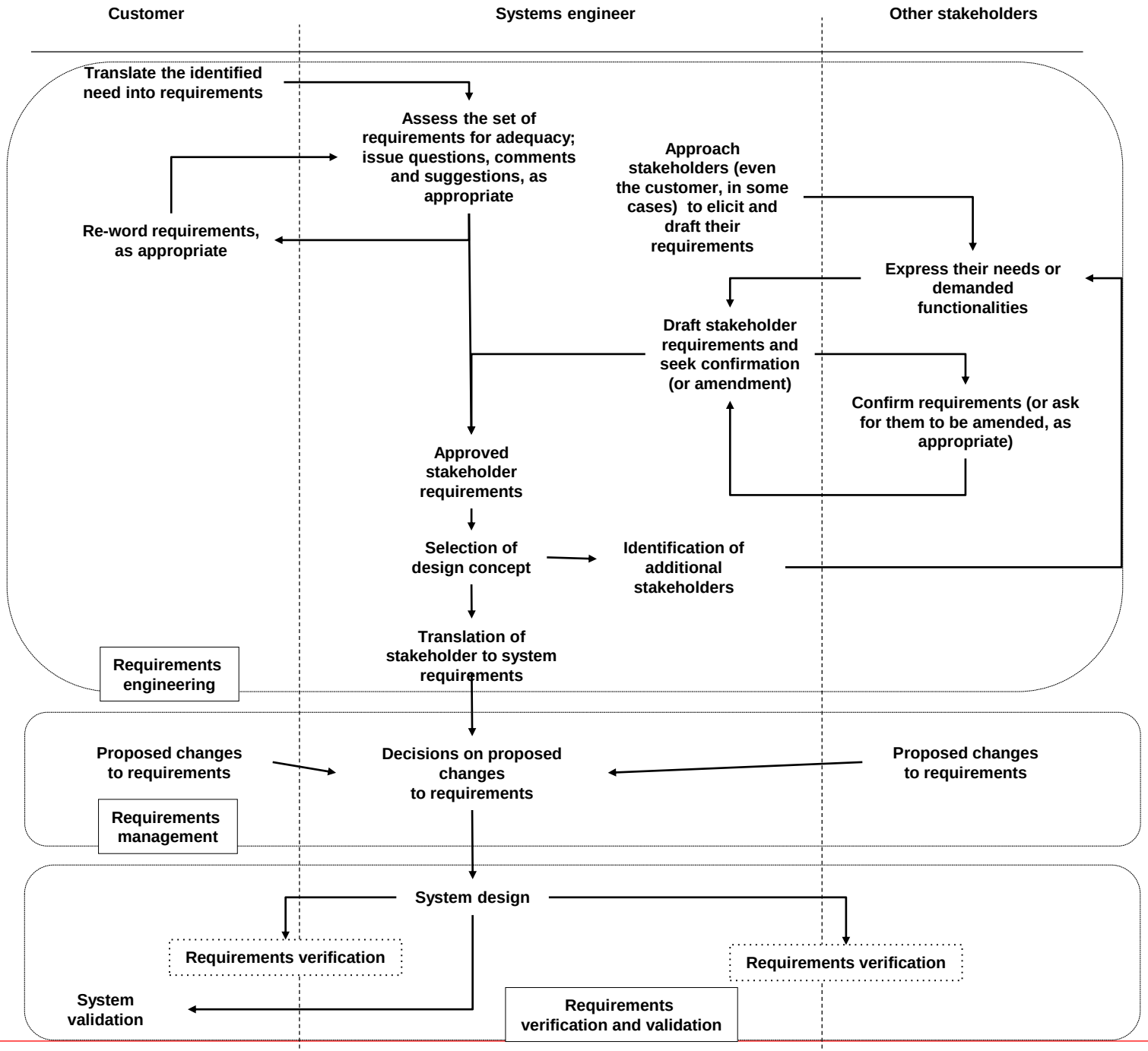
The role of requirements

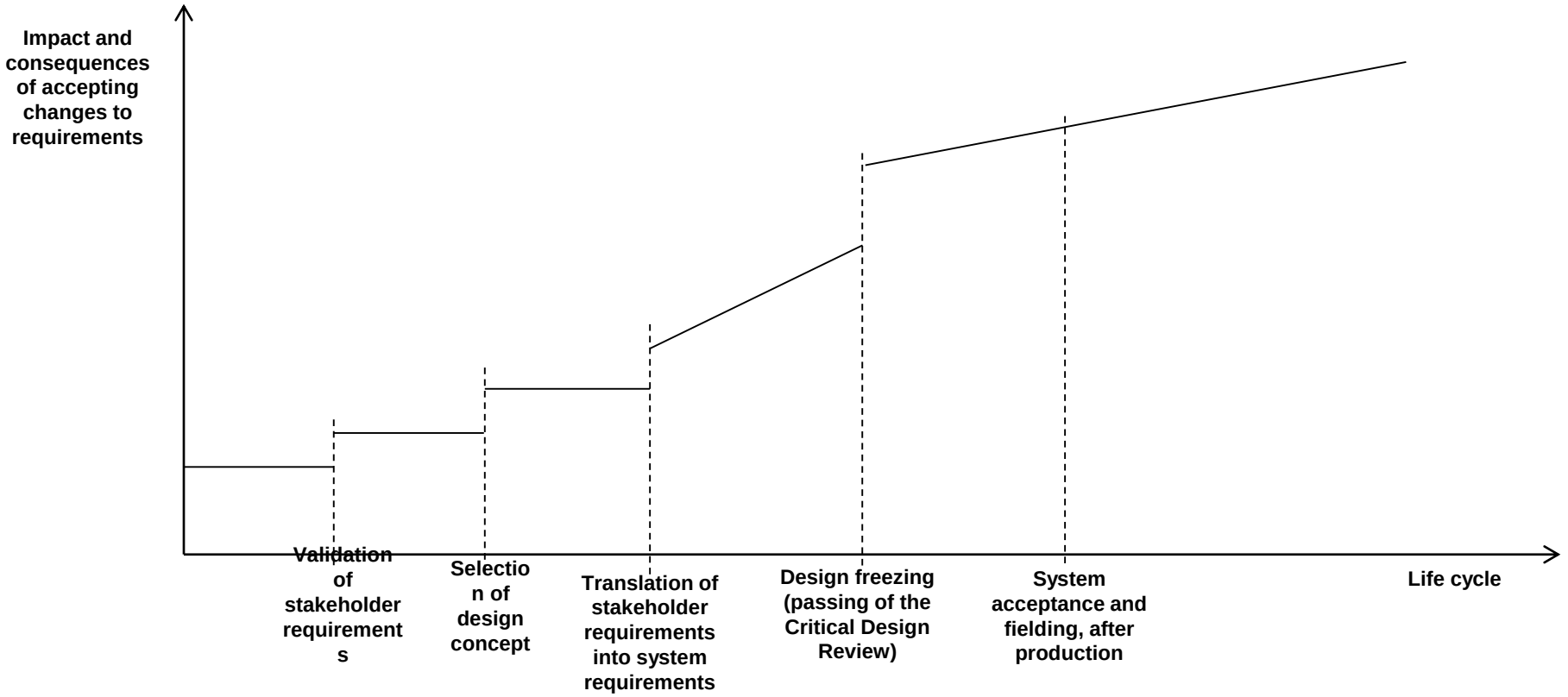
- ✓ **The cornerstone of the systems approach is the correct translation of the need into requirements.**
- ✓ **An incorrect formulation of the need or opportunity in terms of the requirements that define it will contaminate the rest of the design and development effort, leading to ineffectiveness and/or inefficiencies in the designed system.**
- ✓ **The vast majority of the projects that end up derailing in terms of poor performance, schedule delays and/or cost overruns are plagued with inappropriate and/or ill-defined requirements.**
- ✓ **It is essential to ensure a proper understanding of the need or opportunity from the perspective of all involved stakeholders and to express it, reconciling conflicting aspects, into the right set of requirements.**

Requirements engineering and management

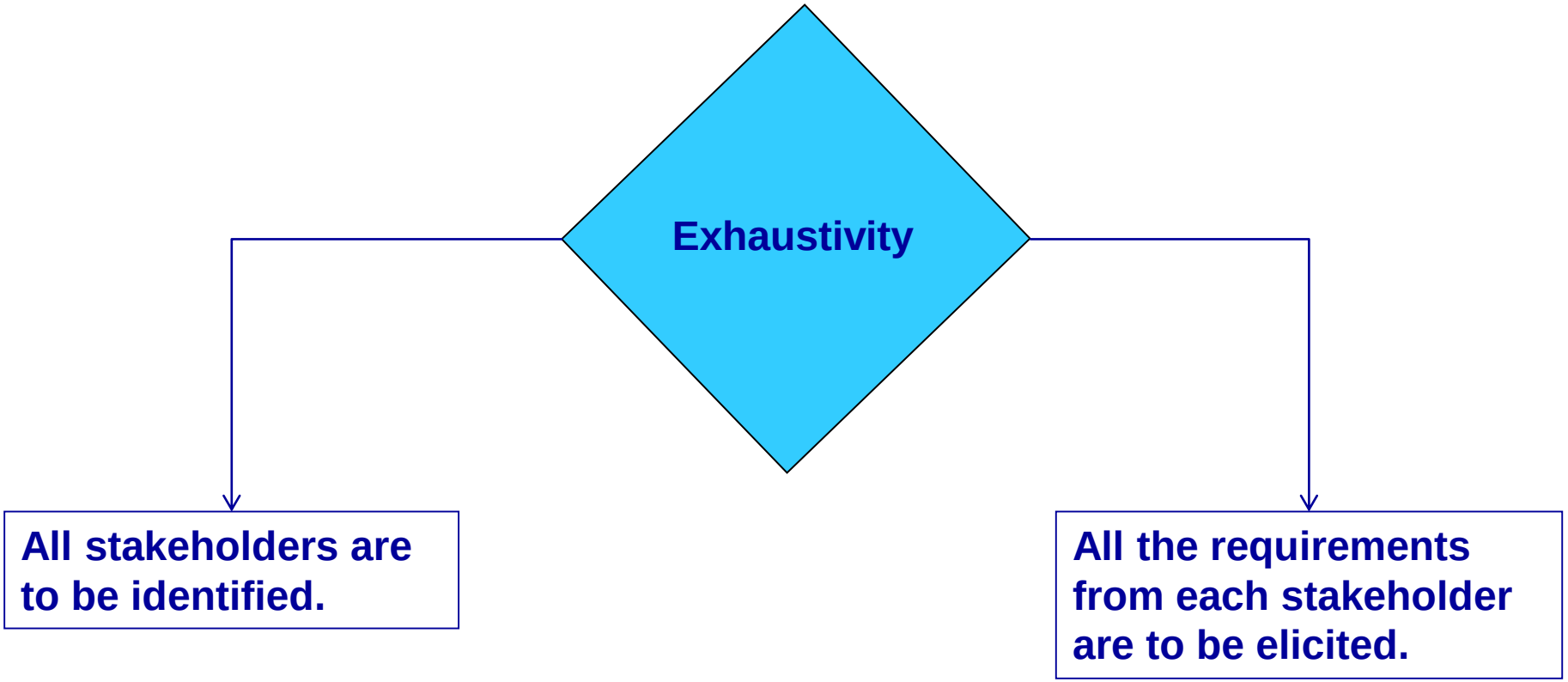
- ✓ **Requirements engineering is the process of developing requirements at both stakeholder and system levels; it comprises eliciting, formulating and validating requirements.**
- ✓ **Requirements management is the process of dealing with proposed changes to the set of approved requirements.**


Customer
Systems engineer
Other stakeholders
Translate the identified need into requirements
Assess the set of requirements for adequacy; issue questions, comments and suggestions, as appropriate
Approach stakeholders (even the customer, in some cases) to elicit and draft their requirements
Re-word requirements, as appropriate
Express their needs or demanded functionalities
Draft stakeholder requirements and seek confirmation (or amendment)
Confirm requirements (or ask for them to be amended, as appropriate)
Approved stakeholder requirements
Selection of design concept
Identification of additional stakeholders
Translation of stakeholder to system requirements
Requirements engineering
Proposed changes to requirements
Decisions on proposed changes to requirements
Proposed changes to requirements
Requirements management
System design
Requirements verification
Requirements verification
System validation
Requirements verification and validation

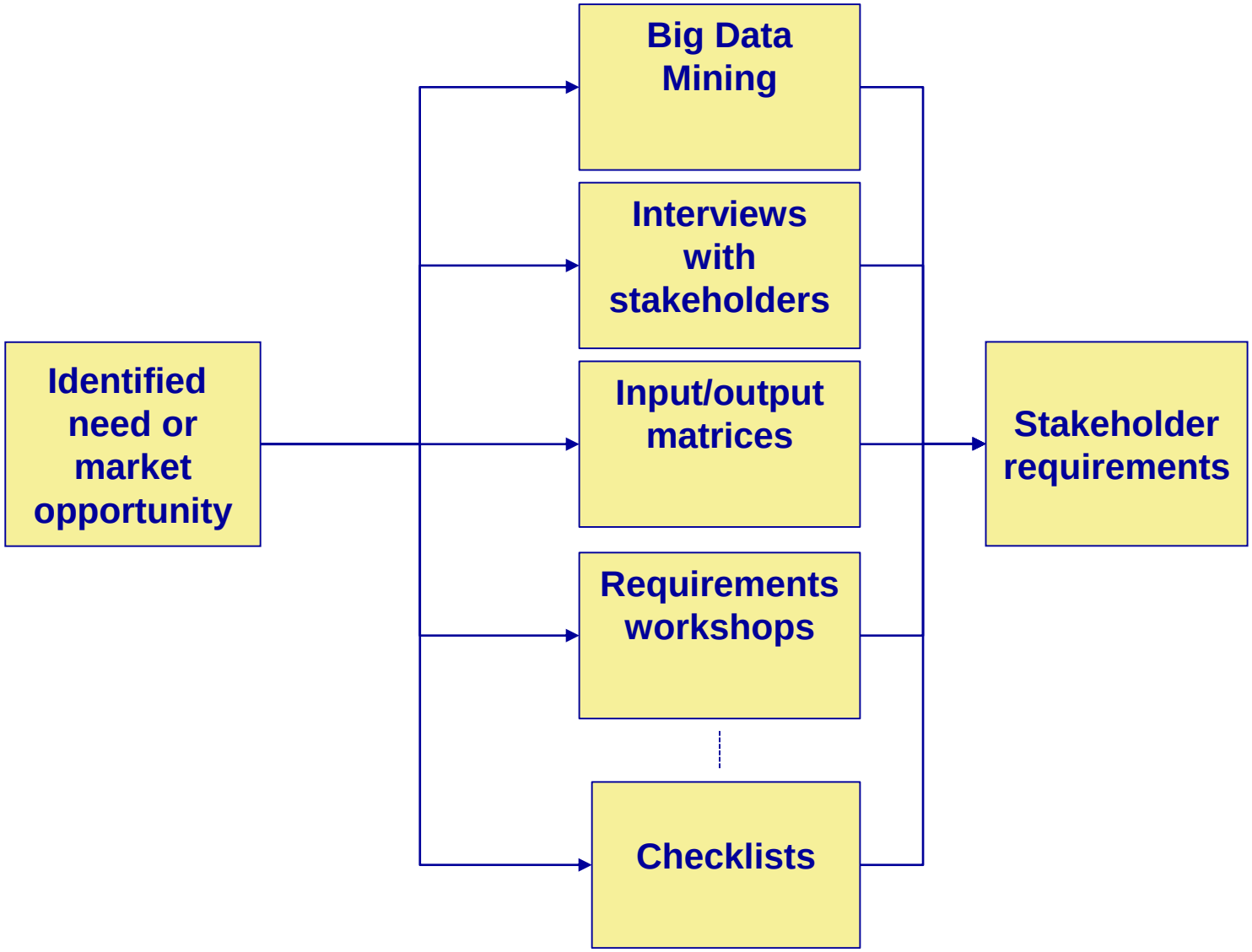
Changes to requirements



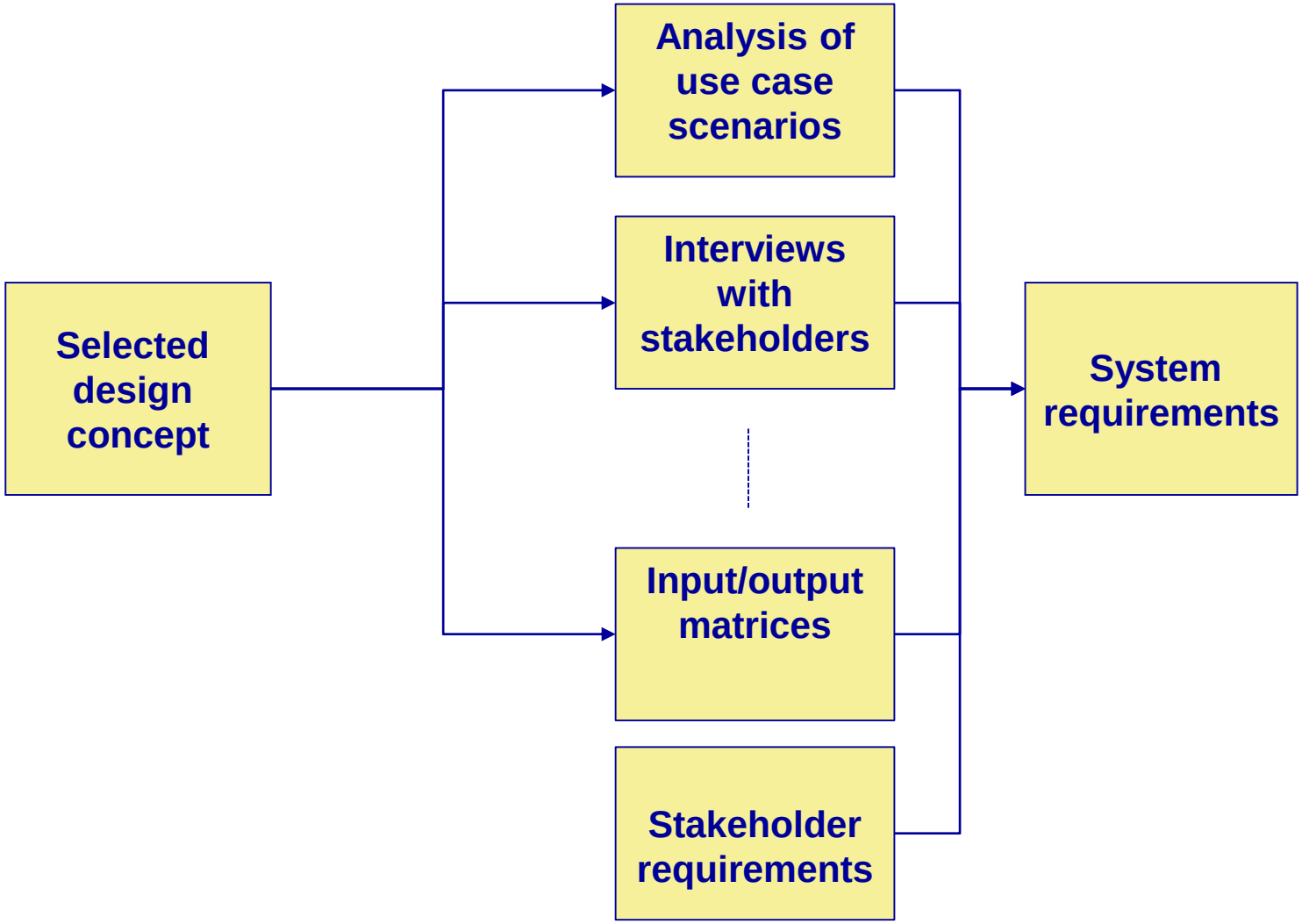
Generation of requirements



Generation of stakeholder requirements



Generation of system requirements



Use case scenarios

- **Use scenarios are descriptions of steps or actions between a user and a system, which lead towards something useful.**
- **Definition of use scenarios are essential in assessing a perceived need or opportunity.**
- **Use scenarios enable the identification of system requirements.**

Use case scenarios: example

- Check account balance.
- Withdraw money.
- Deposit money.
- Order bank transfer.
- Recharge pre-paid cellular phone.
- ...

Use case scenarios: example

Stakeholder	Requirement
User	The ATM shall accept a general user ID
User	The ATM shall accept a unique user ID
Bank	The ATM shall complete the identification of the user in less than 5 seconds
Bank	The ATM shall accept cash deposits or checks from the user
Bank	The ATM shall ask the user for desired activity (cash withdrawal, deposit, transfer)
Bank	The ATM shall use the land phone network to communicate with bank's mainframes
Bank	The ATM shall accept from bank's mainframes input concerning funds or maximum credit available
User	The ATM shall allow the user to cancel the requested activity, before its completion
Bank	The ATM shall have a MTBCF of at least 9 months
Maintenance technician	The ATM shall have a MTTR (active) of less than 4 hours
Bank personnel	The ATM shall permit the re-loading of cash in less than half hour
Security personnel	The ATM shall permit the downloading of deposits in less than half hour
Bank	The ATM shall generate a record of all the transactions
User	If a receipt of the transaction can not be facilitated to the user, the ATM shall indicate so
Bank	The ATM shall have an uninterrupted power supply system covering minimum 2 hours
.....	.....

Big data mining

- **Organizations compile data in many forms (reports, videos, templates, memos, emails, ….).**
- **Frequently those materials contain crucial information on needs, opportunities, challenges, limitations, constraints and so on, as perceived by people designing, producing, using, maintaining, supporting or phasing out systems.**
- **Analyzing the ‘big data’ can help in uncovering requirements for a new system, that could otherwise go unnoticed.**

Input/Output matrices

- **Intended Inputs are resources considered necessary to produce or influence the production, or to obtain the desired outputs, at each system life-cycle phase.**
- **Unintended Inputs are those characteristics, normally beyond the designer's control, that define the environment in terms of operating conditions, and the like, and that can either have a positive or a negative influence in the design.**
- **Desired Outputs are those states or products that are sought at each life-cycle phase.**
- **Undesired Outputs are those resulting characteristics that are not wanted and that, if anticipated in time, can be minimized with regards to their impact on the overall outcome.**

Input/Output matrices

The Input/Output matrices address additional aspects for which it may be necessary to state system requirements.

	Inputs		Outputs	
	Intended	Undesired	Desired	Undesired
Production				
Distribution				
Utilization and maintenance				
Phase-out				

Input/Output matrices: example

Example of Input/Output matrix:

	Inputs		Outputs	
	Intended	Unintended	Desired	Undesired
Electrical	Nominal voltage	Surge voltages	Voltage, current, frequency stability	Electromagnetic interference, electrick shock
Mechanical	Activation force	Shock and vibration	Movement, resistance	Acoustic noise levels
Environmental	Normal temperature range	Extreme temperature and humidity	Particle density, air flow	Heat, effluents

Interviews with stakeholders

A very useful technique to record needs or opportunities and formulate requirements is to interview the stakeholders in teams (at least two people).

Interviewer → Poses questions to the *stakeholder*, progressively, in order to ascertain the true nature and scope of his need or opportunity. Takes few notes.

Annotator → Records the actual responses of the stakeholder and jots down his own observations.

Stakeholder → Expresses his views of the identified need or opportunity.

Requirements workshops

- **Workshops gather the needed people to facilitate a discussion aimed at ascertaining the requirements for a new system.**
- **Workshops need to be effectively managed, to avoid drifting, derailment or personal conflicts.**
- **Workshops have the advantage of having on real time all needed perspectives, leveraging harmonization and prioritization.**

Checklists

- **A checklist is a list of items to be noted, checked, or remembered.**
- **Checklists allow organizations to collect and make explicit experience and lessons learned, for their use in future cases.**
- ***Do not reinvent the wheel .... but be careful with copy-and-paste as it is a source of errors and also kills innovation ...***

Generation of requirements: imagination

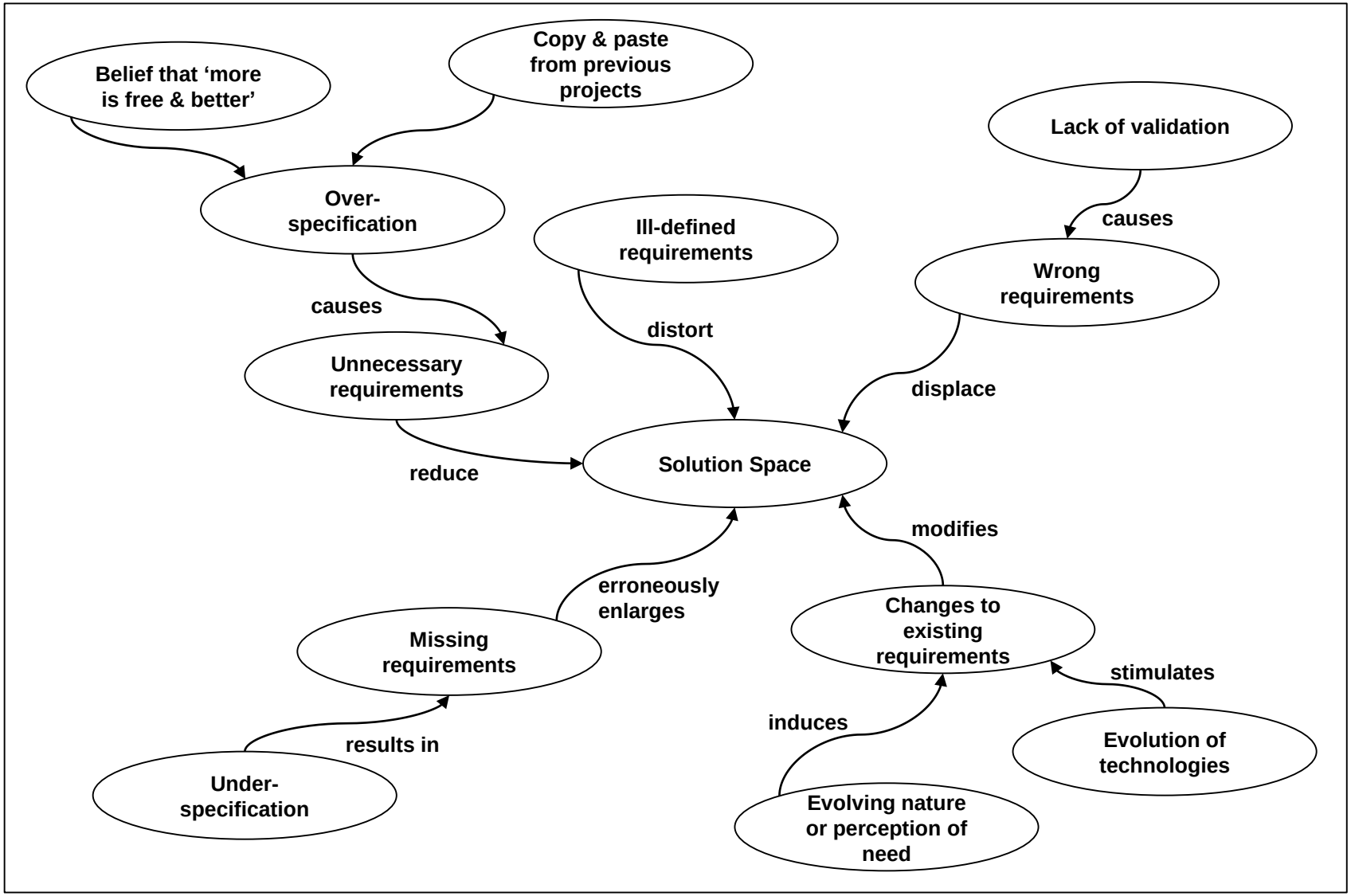
When it is a market opportunity that has been identified there will not be a ‘customer’ to talk to. In those cases, the target population is to be addressed.

Toyota decided in 1983 to create its brand Lexus to compete with luxury automobiles such as Mercedes-Benz and BMW. Toyota sent a team of designers to live in California for several months. The team members rented houses in wealthy neighborhoods, rented high-end cars and lived the type of life of their ‘target population’. After five months they returned to Japan with the first design proposals; Lexus was a great success from its launching.

The number of requirements

- **How many requirements are appropriate to define a need or opportunity?**
- **Is ‘the more, the better’?**
- **Unnecessary requirements reduce the solution space, and increase costs.**
- **Ill-defined requirements displace the solution space.**

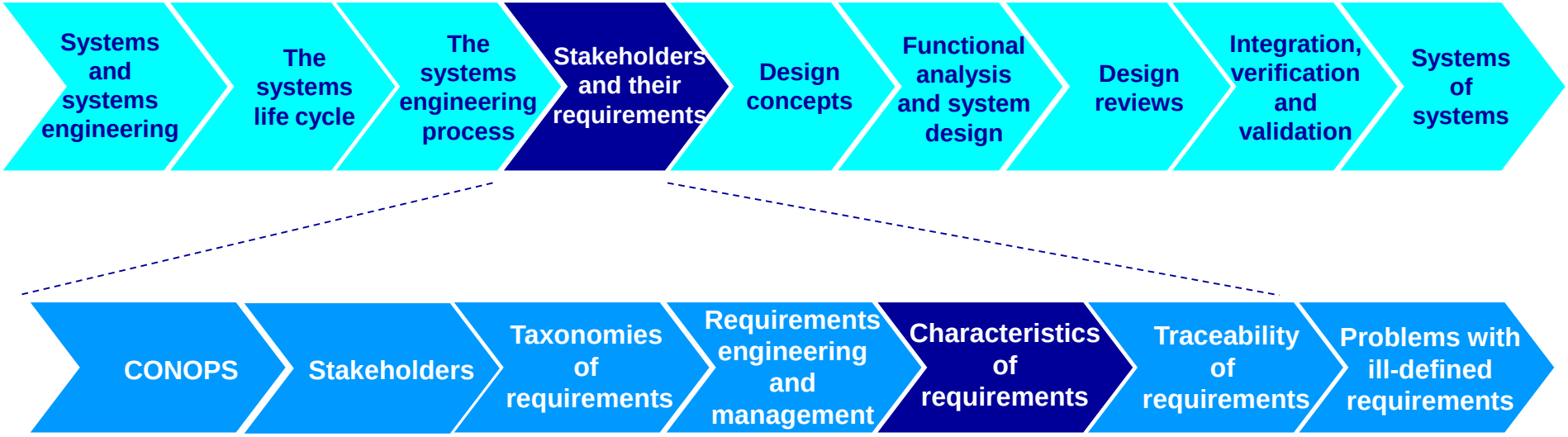
Inadequate requirements and the solution space



Lack of synthesis capability

‘My apologies for having written such a long letter; I did not have the time to write a short one’

(Sir Winston Churchill)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Characteristics of stakeholder requirements

- **Requirements are to describe what has to be done, not how!**
- **Requirements are to be atomic (unitary), addressing only one concept. (This is recommendable for stakeholder requirements and mandatory for system requirements).**
- **Requirements are to be unique, as repetition of requirements increases likelihood of conflicts and misunderstandings.**
- **Requirements are to be traceable to their owners or originators.**
- **Requirements are to be approved by the relevant stakeholder (owner), to ensure they capture the end need.**
- **Requirements are to be complete, stating all conditions under which it applies.**

Characteristics of stakeholder requirements

- **Requirements are to be formulated in a positive way, avoiding negative statements (unless a negative statement offers absolutely no doubt about its meaning and purpose).**
- **Requirements are to be concrete, avoiding all ambiguity (certain fuzziness is acceptable in stakeholder).**
- **Requirements are to be prioritizable; they might be classified as ‘must’, ‘desirable’ and ‘nice to have’.**

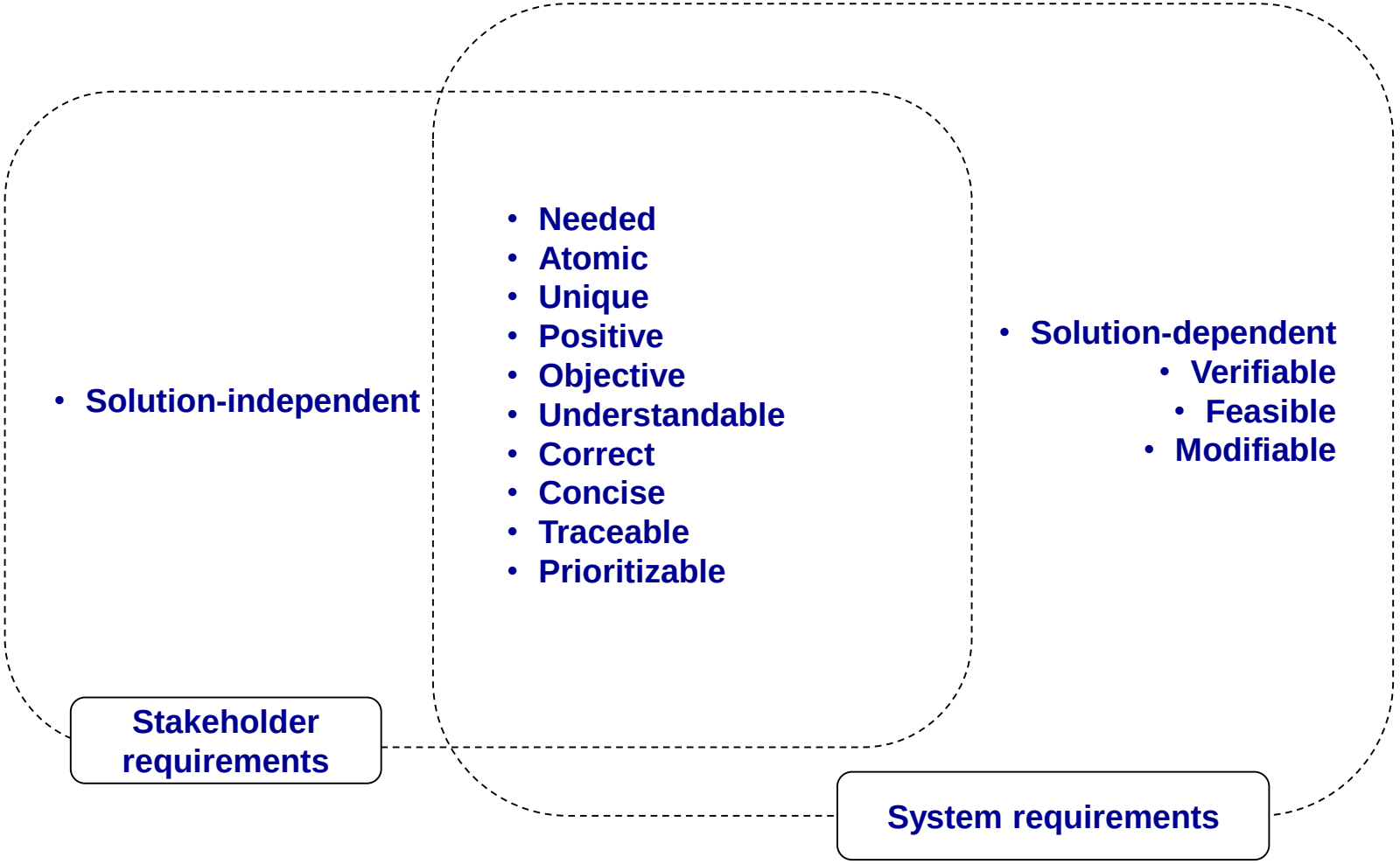
Characteristics of system requirements

- **Requirements are to be concept-dependent.**
- **Requirements are to be verifiable; whenever necessary, the verification method is to be stated together with the requirement.**
- **Requirements are to be feasible.**
- **Requirements are to be modifiable.**

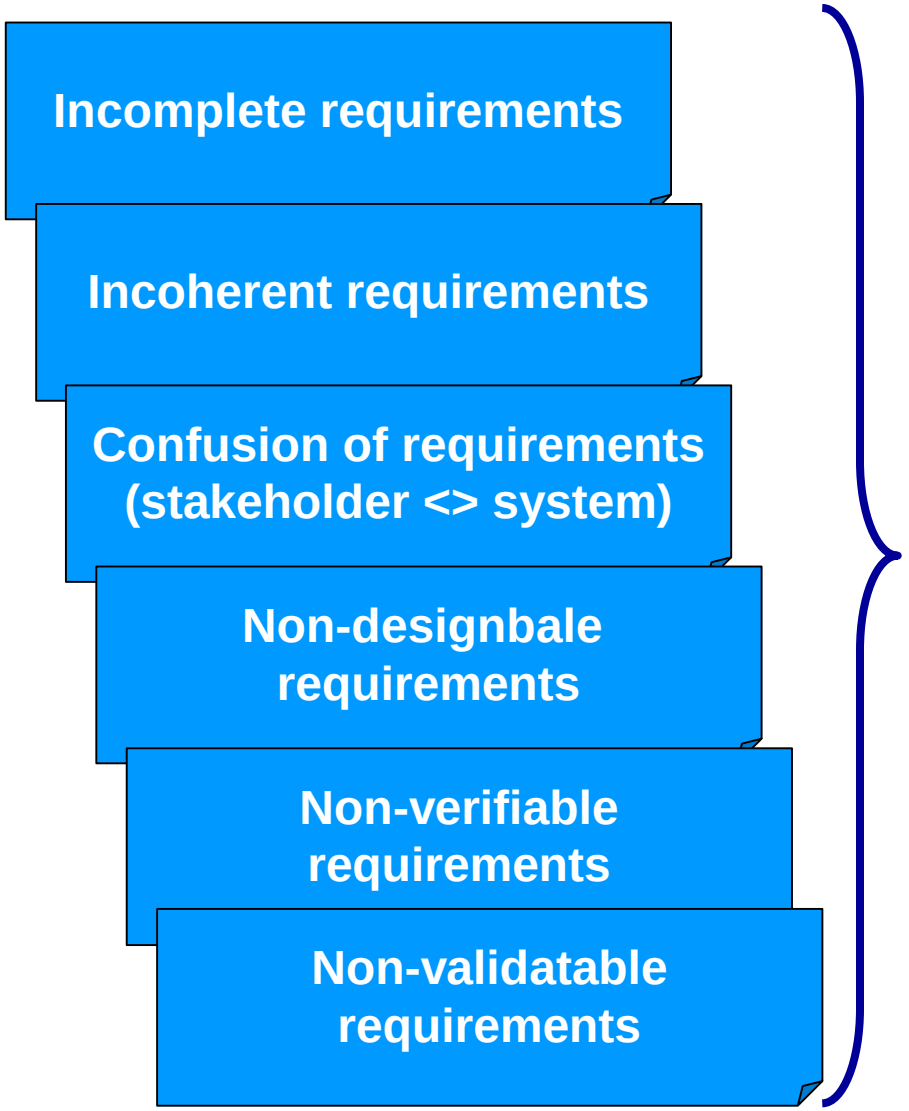
Characteristics of the set of requirements

- **Complete. The identified need or the perceived opportunity is to be fully explained through the set of requirements.**
- **Coherent. No conflicts or contradictions are to be present in the set of requirements at any level (stakeholder or system), which is the same as to say that the set has to be consistent.**
- **Structured. A well-organized set of requirements will be easier to understand than a poorly-structure one. Requirements are to be organized in a logical manner that facilitates their understanding.**
- **Non-redundant. There should be no repetitions; each aspect is to be covered just once.**

Characteristics of requirements



Requirements assessment

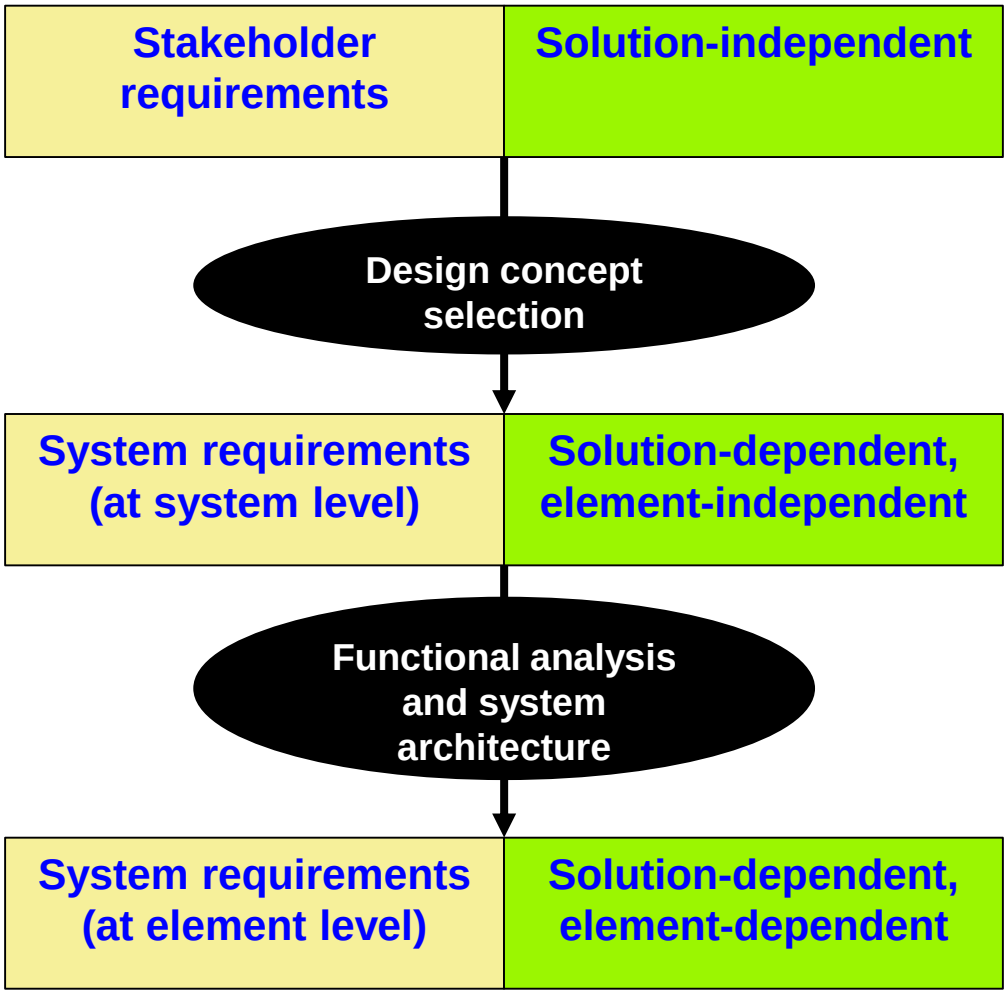


To design (or to purchase) a system in these conditions implies the undertaking of unacceptable risks!

Stakeholder and system requirements

- **Writing stakeholder requirements is easy, in relative terms, as it implies stating the capabilities needed.**
- **Writing system requirements is difficult, in relative terms, because they are formulated for a selected design concept and consequently the writing of those requirements will demand some knowledge of the specific solution adopted.**

Stakeholder and system requirements



Stakeholder requirements template

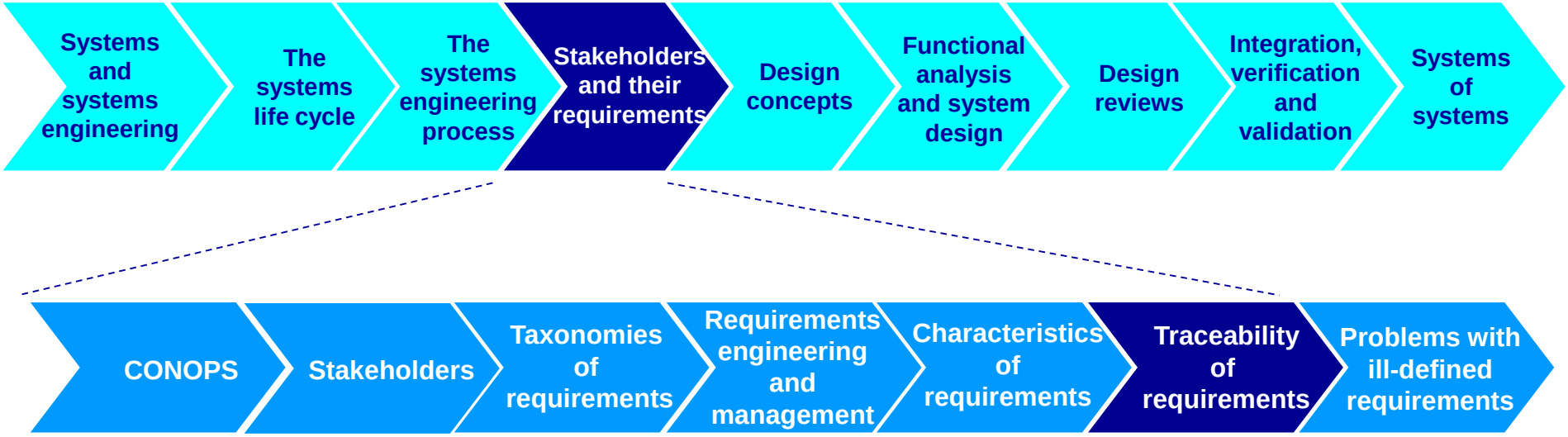
Stakeholder requirement code		**Stakeholder code**		**Stakeholder**	
Stakeholder requirement					
Stakeholder requirement type			**Stakeholder requirement priority**		
Rationale					
Stakeholder requirement writer				**Stakeholder requirement date**	
Stakeholder requirement engineering technique					
Stakeholder requirement status		**Stakeholder requirement history**			

Stakeholder requirements simplified template

Stakeholder requirement code		**Stakeholder code**		**Stakeholder**	
Stakeholder requirement					
Stakeholder requirement type			**Stakeholder requirement priority**		
Rationale					

System requirements template

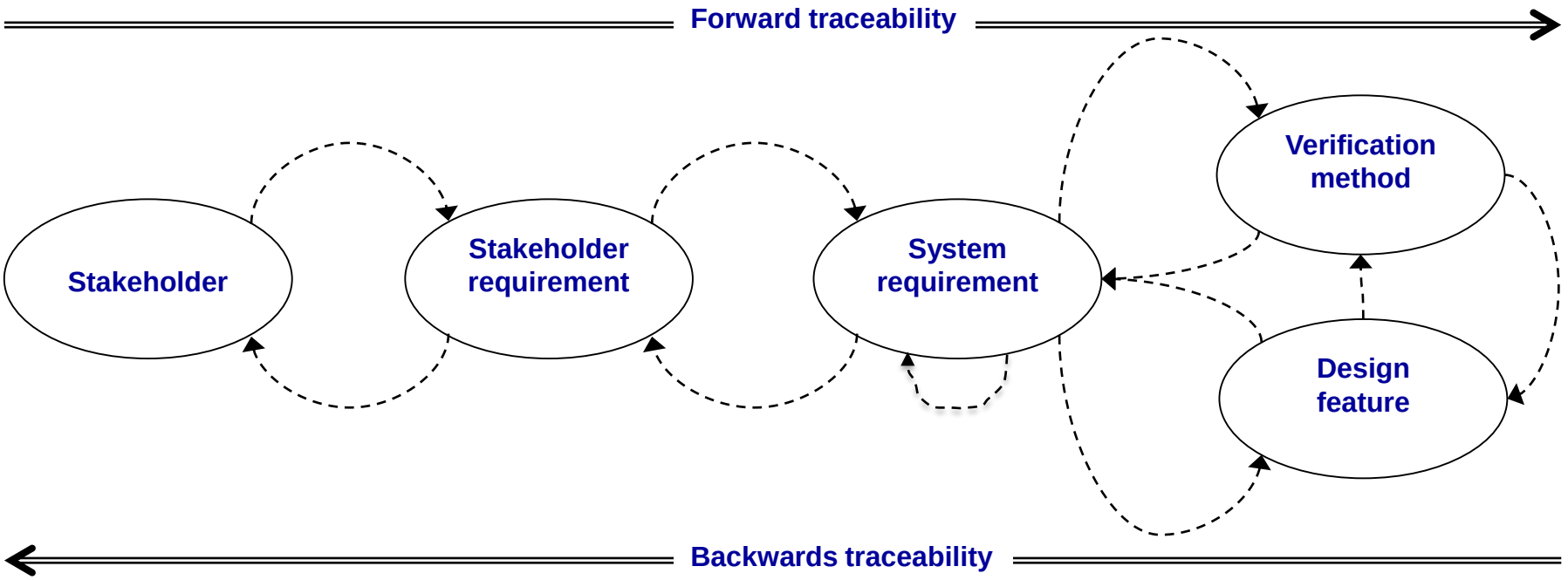
Stakeholder requirement code			**System requirement code**		
Stakeholder requirement					
Stakeholder requirement type			**Stakeholder requirement priority**		
Design concept					
System requirement					
Verification method 1	**Life cycle phase applicability**		**Verification method code**		
	Verification method description				
Verification method 2	**Life cycle phase applicability**		**Verification method code**		
	Verification method description				
System requirement writer			**System requirement date**		
System requirement status		**System requirement history**			


Systems and systems engineering
The systems life cycle
The systems engineering process
Stakeholders and their requirements
Design concepts
Functional analysis and system design
Design reviews
Integration, verification and validation
Systems of systems
CONOPS
Stakeholders
Taxonomies of requirements
Requirements engineering and management
Characteristics of requirements
Traceability of requirements
Problems with ill-defined requirements

Traceability of requirements

- **Traceability means capability of linking requirements to originators and to effects in the design of the system.**
- **Requirements are to be fully traceable forward and backwards.**

Traceability of requirements



Traceability of requirements

Traceability is essential to support:

-re-formulation with stakeholders of requirements not understood.

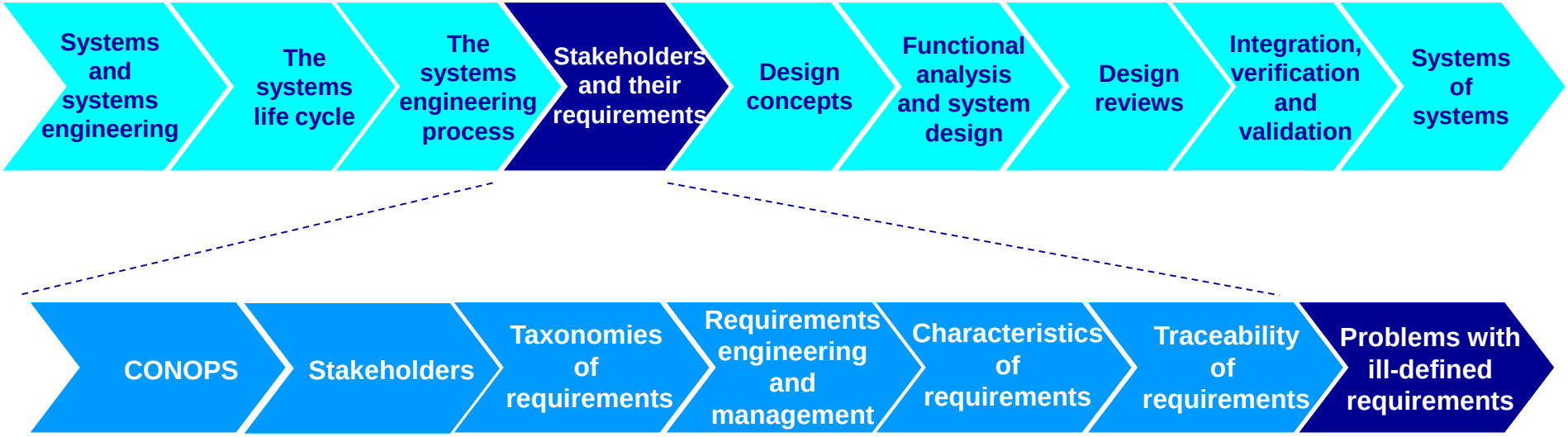
-re-definition with stakeholders of requirements that can’t be met.

-performance of design reviews in which evidence of fulfillment of requirements is presented to the relevant stakeholders.

-elaboration of progress reports.

-changes to linked system requirements.

-...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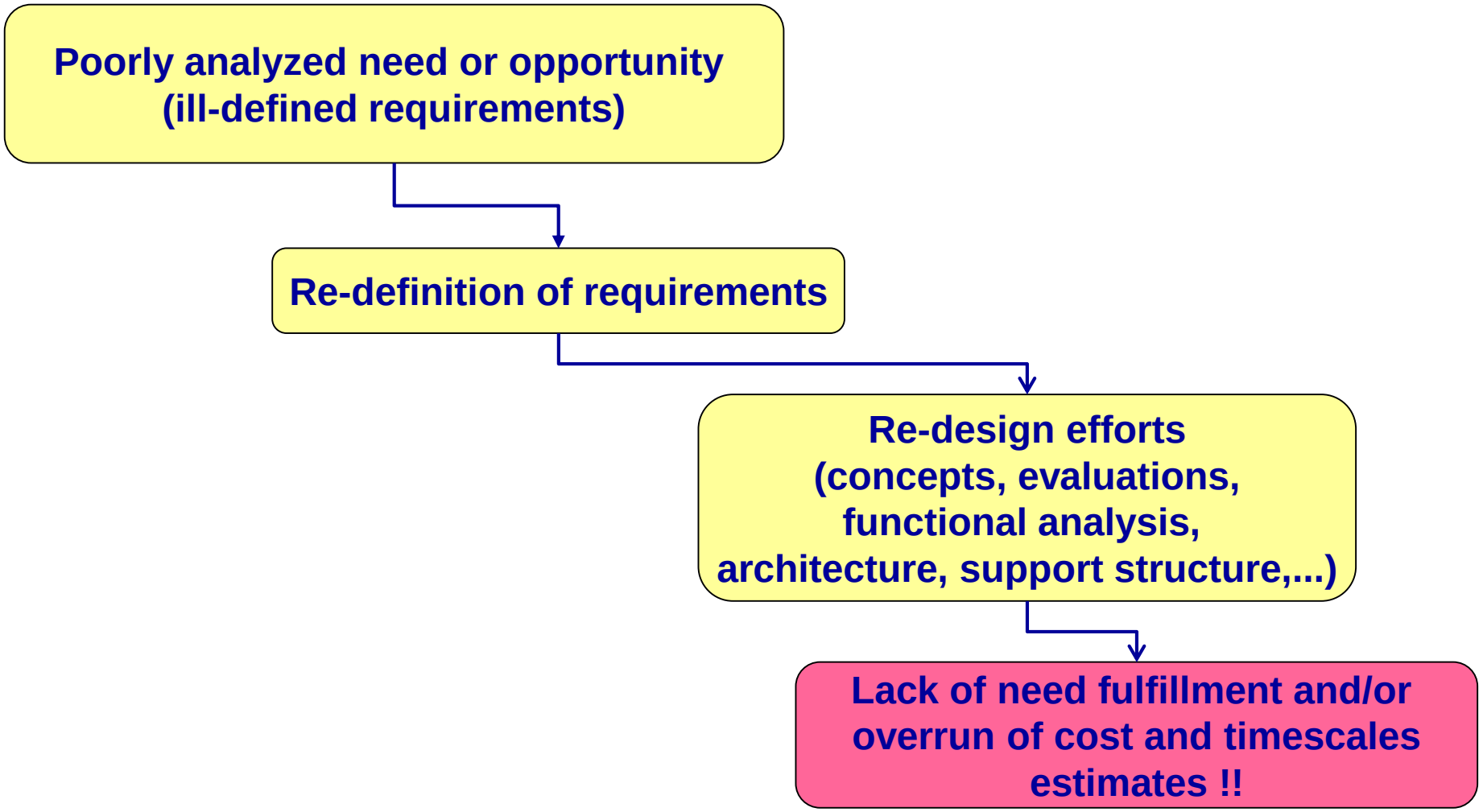
Problems with ill-defined requirements

Ill-defined requirements

Among the frequent errors that end up translating in failure to fulfill the identified need or the perceived opportunity are:

- **the incomplete identification of stakeholders**
- **the confusion of high-level and detailed requirements**
- **the inadequacy in the formulation of the requirements (ill-defined requirements)**

Ill-defined requirements



Requirements

First state well …..

It makes no sense to be exact about something when you do not even know what you are talking about.

(John von Neumann)

... and then measure well ...